High aboveground carbon stock of African tropical montane forests

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Supplementary Information Table S1 | Correlations between different recent remote-sensing derived carbon maps and between these maps and AfriMont plot aboveground carbon stock estimates. Pairwise Spearman's rank correlation coefficients are shown.

		Dated	**Spatial resolution**	**1**	**2**	**3**	**4**
1	Harris et al. (ref. [65])	2000	30 m	-			
2	ESA CCI Biomass map (ref. [66])	2017	100 m	**0.29**			
3	Saatchi et al. (ref. [67])	2007/2008	1,000 m	0.04	**0.35**		
4	Avitabile et al. (ref. [68])	2000-2010	1,000 m	**0.09**	**0.45**	**0.59**	
5	AfriMont plots (unaggregated, *n*=666)			**0.19**	-0.11	**-0.13**	**-0.12**

bold: significant at *P* < 0.01

Supplementary Information Table S2 | Estimated differences in aboveground carbon (AGC) stocks amongst continents and forest elevation category based on plot networks. Coefficients are from a linear mixed-effects model, where African montane forests are taken as the model intercept; other coefficients show differences from this intercept. 95% confidence intervals and *P*-values were estimated by bootstrapping the fitted model. AGC-stocks were log-transformed prior to analysis, and coefficients relate to the log-transformed variable.

Term	**Estimate**	**LCL**	**UCL**	***P***
Intercept - Africa montane	5.007	4.921	5.101	<0.001
Difference:				
Africa lowland	0.054	-0.066	0.170	0.360
Southeast Asia montane	-0.037	-0.287	0.202	0.793
Southeast Asia lowland	0.311	0.142	0.472	<0.001
Neotropics montane	-0.531	-0.655	-0.411	<0.001
Neotropics lowland	-0.276	-0.386	-0.175	<0.001

Supplementary Information Table S3 | Difference in contribution of different size classes to aboveground carbon (AGC) stocks and number of stems between montane and lowland forests in Africa. Coefficients are from linear mixed-effects models of the proportion contribution of a given size class against forest elevation category are shown. Proportions were square-root transformed prior to analysis, and coefficients relate to the transformed variables. 95% confidence intervals and *P*-values were estimated by bootstrapping the fitted models.

Variable	**Size class (cm)**	**Difference from lowland**	**LCL**	**UCL**	***P***
AGC-stocks	<30	-0.018	-0.071	0.031	0.474
	30-50	-0.004	-0.044	0.036	0.835
	50-70	-0.024	-0.066	0.016	0.240
	>70	-0.011	-0.100	0.075	0.799
Stems	<30	-0.031	-0.059	-0.004	0.026
	30-50	0.030	0.003	0.056	0.022
	50-70	0.014	-0.015	0.044	0.378
	>70	0.018	-0.019	0.055	0.334

Supplementary Information Table S4 | Relationship between elevation and aboveground carbon (AGC) stocks, stem density and density of large stems (>70 cm diameter, SD_{70}) for the AfriMont dataset. Relationships are from linear mixed-effects models with site as a random effect, and relationship with elevation allowed to vary with site. Response variables were log-transformed, and elevation was scaled by subtracting its mean and dividing by its standard deviation. 95% confidence intervals and P values were obtained by bootstrapping the fitted models. Polynomial and linear models were compared using likelihood ratio tests; slopes are from linear models. RWE: Rwenzori Mts, VRG: Virunga Mts, see Table S5.

	All data					**Excluding RWE and VRG**				
Response variable	**Slope**	**LCL**	**UCL**	***P***	**Significance of non-linear relationship**	**Slope**	**LCL**	**UCL**	***P***	**Significance of non-linear relationship**
AGC- stocks	-0.043	-0.140	0.064	0.418	$\chi^2_1 = 0.129$, $P = 0.720$	-0.039	-0.154	0.076	0.511	$\chi^2_1 = 0.440$, $P = 0.507$
Stem density	-0.036	-0.118	0.042	0.350	χ^2_1 0.002, $P = 0.963$	-0.044	-0.135	0.046	0.308	$\chi^2_1 = 0.142$, $P = 0.706$
SD_{70}	-0.059	-0.260	0.148	0.599	$\chi^2_1 = 0.105$, $P = 0.746$	0.022	-0.202	0.236	0.849	$\chi^2_1 = 4.005$, $P = 0.045$*

* Polynomial model: $SD_{70} = 2.756 – 0.575$ Elevation + 2.060 Elevation^2

Supplementary Information Table S5 | Site attributes of the AfriMont plot network. Plots size refers to planimetric area. Elevation from SRTM v3 at 3 arc-sec (~90m) resolution.

Country	Site	Code	No. plots	Plots size (ha)		Elevation (m asl)	Elephant Presence	Year	Plot Setup	Main reference
Burundi	Kibira NP	BUR	7	1.8-3.6	a	1900-2500	0	2012	T	Ref. [74]
Cameroon	Babanki	BAB	2	0.72-1	a	2000-2350	0	2008-2009	R	unpublished
	Bakossi Mts	BAK	12	0.91-0.99		1000-1400	0	2016	Sub	Ref. [75]
	Mt Cameroon	CAM	10	0.5-1.1	a	960-2270	1 (some)	2011	T	Ref. [76]
	Mt Mbam	MBA	2	0.23-0.54	a	1760-2220	0	2017	E	Ref. [77]
	Nguti	NGI	3	0.80-0.87		870-940	1	2013	other	unpublished
	Mt Oku	OKU	2	0.39-0.54	a	2200-2700	0	2017	E	Ref. [77]
	Rumpi Hills	RUM	4	0.95-0.99		1350-1750	0	2015	Sub	Ref. [78]
	Takamanda	TNP	2	1		1190-1290	1	2012	other	Ref. [4]
DRC	Itombwe Mts	ITO	8	0.9		1100-2470	1 (some)	2019	E	unpublished
	Kahuzi-Biega NP	KAH	29	0.9		1630-2430	0	2014	R	Ref. [79]
Ethiopia	Bonga	BON	5	0.19-0.82	a	1570-2660	0	2001-2005	T	Ref. [80]
	Harena Forest (Bale)	HAR	4	0.19-0.27	a	800-1120	0	2001-2005	T	Ref. [80]
	Jaba	JAB	1	0.26	a	1500-1650	0	2001-2005	R	Ref. [80]
	Kafa Biosphere Reserve	KAF	7	0.24-0.35	a	1470-2670	0	2011	R	Ref. [81]

	Munessa Forest (Bale)	KUK	1	0.49	a	2300-2310	0	2011	other	Ref. [82]
	Berhane–Kontir	SHE	6	0.19-0.23	a	1520-2090	0	2001-2005	T	Ref. [80]
	Yayu Coffee Forest	YAY	1	0.99		1500	0	2014	other	unpublished
Guinea	Mt Nimba	NIM	2	0.36-0.42	a	760-1060	0	2011	Sub	unpublished
Kenya	Aberdares Mts	ABE	5	0.35-0.77	a	2270-3020	1	2014	R	Ref. [83]
	Mt Kulal	KUL	9	0.2		1800-2150	0	2016	E	Ref. [84]
	Mt Marsabit	MAR	6	0.2		1070-1400	1	2016	E	Ref. [84]
	Mau Forest Complex	MAU	3	0.27-0.45	a	2080-2850	1	2012	R	Ref. [85]
	Mt Nyiro	NYI	9	0.2		2150-2710	0	2016	E	Ref. [84]
	Taita Hills	TAI	6	0.2-1.6	a	1550-2170	0	2013-2015	R	Ref. [86]
Mozambique	Mt Lico	LIC	1	0.11	a	900-1000	0	2018	Sub	unpublished
	Mt Mabu	MAB	2	0.11-0.18	a	1000-1320	0	2008	Sub	unpublished
	Mt Muli	MUL	1	0.11	a	1200-1280	0	2018	Sub	unpublished
Nigeria	Ngel-Nyaki FR	NGE	1	1		1570	0	2015	other	Ref. [87]
Rwanda	Nyungwe NP	NYU	5	0.5		1950-2480	0	2015	Sub	Ref. [88]
	Virunga Mts	VRG	6	0.99		2470-3390	1	2015	Sub	unpublished (TEAM)
Tanzania	Nguu	GUU	1	0.38		950	0	2009	other	Ref. [16]
	Mt Kilimanjaro	KIL	13	0.19-0.25		1630-2800	0	2010-2013	E	Ref. [89]
	Udzungwa Mts	UDZ	7	0.85-0.97		1140-1970	0	2007-2010	E	Ref. [16]

	Ukaguru	UKA	2	0.37-0.39		1190-1640	0	2009	Sub	Ref. [16]
	Uluguru	ULU	2	0.18-0.26		970-2110	0	2009	Sub	Ref. [16]
	Usambara Mts	USA	4	0.97-0.99		1050-1830	0	2010	E	Ref. [16]
Uganda	Budongo FR	BUD	1	1.86		1090	0	2008	other	Ref. [90]
	Bwindi NP	BWI	6	1		1420-2380	1	2009	Sub	Ref. [52]
	Kibale NP	KIB	4	0.24		1210-1540	1	2013	other	Ref. [46]
	Mpanga	MPG	1	0.63		1180	0	2006	other	Ref. [91]
	Rabongo FR	RAB	7	1		950-990	1	1992-1993	R	Ref. [92]
	Rwenzori Mts	RWE	4	0.61-0.86	a	1800-3900	1 (some)	2019	E	unpublished
Zimbabwe	Chirinda FR	CHI	12	0.24		1090-1250	0	1995	R	unpublished

[a] plots were originally <0.2 ha and were aggregated into larger plots, see methods for details. Elevation for these plots refers to original unaggregated plots.

FR: Forest Reserve, NP: National Park.

For elephant presence: 1: presence in all plots in the site, some: some plots in the site, 0: absence. Presence in 2019 was estimated by co-authors and refers to variable densities of resident and migrant individuals of both the savanna elephant (*Loxodonta africana*) and the smaller forest elephant (*L. cyclotis*). In some sites elephants are confined and highly abundant (e.g. in ABE, where there is an electric fence), conditions which might not have occurred under 'natural' circumstances in the past.

Plot setup refers to: random or stratified random (R), plots positioned along transects (T), plots established within elevation bands (E), subjective measures such as choosing an area of forest considered representative of the wider area (Sub), and other strategies (1 plot sampled per site or unclear strategy, other).

Supplementary Information Table S6 | Information on the AfriTRON plots used.

Country	Code	Latitude	Longitude	Elevation (m asl)	Plot size (ha)
Cameroon	DJL-01	3.1	13.6	544	1
	DJL-02	3.1	13.6	606	1
	DJL-03	3	13.6	569	1
	DJL-04	3	13.6	595	1
	DJL-05	3	13.6	604	1
	DJL-06	3	13.6	585	1
	DJA-05	3.2	12.6	640	1
	DJA-07	2.9	13.3	580	0.5
	DJA-09	3.1	13.6	660	1
	CAM-02	2.3	9.9	38	1
	EJA-04	5.7	9	142	1
	EJA-05	5.7	9	166	1
	NGI-12	5.2	9.7	724	1
	NGO-04	2.6	14.1	491	1
	NGO-01	2.6	14.1	516	1
	NGO-02	2.6	14.1	574	1
	NGO-05	2.6	14.1	518	1
	NGO-06	2.6	14.1	529	1
	DNG-02	5.2	13.5	716	1
	MIT-01	2.4	13.5	618	1
	DJA-01	3.3	12.9	590	2.25
	DJA-02	3.3	12.9	590	2.5
	DJA-03	3.3	12.9	570	2.5
	DJA-04	3.3	12.9	610	2.5
	CAM-01	2.3	9.9	58	1
	CAM-03	2.4	9.9	100	1
	DJK-01	3.3	12.7	647	1
	DJK-02	3.3	12.7	722	1
	DJK-03	3.4	12.7	639	1
	DJK-04	3.4	12.7	639	1
	DJK-05	3.3	12.8	779	1
	DJA-17	2.9	13.3	575	0.2
	TNP-11	6.2	9.3	166	0.92
	DJK-06	3.3	12.8	639	1
	TNP-14	6.1	9.3	158	0.8
	MDJ-01	6.2	12.8	789	1
	MDJ-03	6	12.9	757	1
	MDJ-07	6	12.9	764	1
	MDJ-10	6	12.9	767	0.4
	BIS-01	3.3	12.5	633	1
	BIS-02	3.3	12.5	633	1
	BIS-03	3.3	12.5	660	1
	BIS-04	3.3	12.5	634	1

	BIS-05	3.3	12.5	658	1
	BIS-06	3.3	12.5	574	1
	TNP-06	6.1	9.4	187	1
	TNP-07	6.1	9.4	381	1
	TNP-10	6.2	9.3	185	1
	TNP-12	6.1	9.2	133	1
	TNP-13	6.1	9.2	139	1
	TNP-15	6.1	9.3	182	1
	NGI-01	5.3	9.5	248	1
	NGI-02	5.3	9.5	258	1
	NGI-03	5.4	9.6	251	1
	NGI-04	5.4	9.6	511	1
	NGI-05	5.4	9.6	397	1
	NGI-06	5.2	9.7	531	1
	NGI-07	5.2	9.7	790	1
	NGI-08	5.2	9.7	669	1
DRC	YOK	0.3	25.3	418	9
	ITU-01	1.4	28.4	750	0.25
	ITU-02	1.4	28.5	750	0.44
	ITU-03	1.3	28.6	750	0.5
	ITU-04	1.4	28.4	750	0.5
	ITU-05	1.4	28.5	750	0.5
	ITU-06	1.4	28.6	750	0.5
	SNG-01	-1.7	20.6	371	1
	SNG-02	-1.7	20.6	365	1
	SNG-03	-1.7	20.6	420	1
	SNG-04	-1.7	20.5	384	1
	SNG-05	-1.7	20.5	361	1
	SNG-06	-1.7	20.5	360	1
	SNG-07	-1.7	20.5	362	1
	SNG-08	-1.7	20.5	382	1
	SNG-09	-1.7	20.5	374	1
	KSN-01	0.3	25.3	449	0.2
	KSN-02	0.3	25.3	455	0.2
	KSN-05	0.3	25.3	452	0.2
	KSN-06	0.3	25.3	440	0.2
	YGB-08	0.8	24.5	460	1.02
	YGB-14	0.8	24.5	438	1.07
	YGB-15	0.8	24.5	464	1.07
	YGB-16	0.8	24.5	427	1.02
	YGB-17	0.8	24.5	466	1.03
	YGB-18	0.9	24.5	427	1.01
	YGB-24	0.8	24.5	464	1.07
	YGB-25	0.8	24.5	477	0.99
	YGB-26	0.8	24.5	435	1
	YGB-27	0.8	24.5	417	1

	YGB-28	0.8	24.5	489	1.02
Liberia	GBO-19	5.4	-7.6	175	0.78
	GBO-02	5.4	-7.6	172	1
	GBO-08	5.4	-7.6	174	1
	GBO-01	5.4	-7.6	171	0.98
	GBO-03	5.4	-7.6	175	0.69
	GBO-04	5.4	-7.6	175	0.42
	GBO-10	5.4	-7.6	175	0.46
	GBO-11	5.4	-7.6	175	0.67
	GBO-13	5.4	-7.6	175	0.56
	GBO-14	5.4	-7.6	175	0.83
	GBO-15	5.4	-7.6	175	0.71
	GBO-16	5.4	-7.6	161	0.44
	GBO-18	5.4	-7.6	175	0.62
	GBO-20	5.4	-7.6	175	0.59
	CVL-01	6.2	-8.2	257	0.89
	CVL-10	6.2	-8.2	262	0.78
	CVL-11	6.2	-8.2	260	0.85
	CVL-08	6.2	-8.2	281	1
	GBO-12	5.4	-7.6	167	1
	GBO-05	5.4	-7.6	151	0.88
	GBO-06	5.4	-7.6	154	0.64
	GBO-07	5.4	-7.6	176	0.43
	GBO-09	5.4	-7.6	176	0.2
	GBO-17	5.4	-7.6	160	0.84
Nigeria	OBE-83	5.3	8.5	121	1
	OBE-84	5.3	8.5	125	1
Tanzania	UDJ-01	-8.6	35.9	510	0.25
	UDJ-02	-8.6	35.9	630	0.25
	VTA-01	-7.8	37	296	0.28
	VTA-02	-7.8	36.9	583	0.52
	VTA-03	-7.8	36.9	670	0.8
	VTA-04	-7.7	36.9	608	0.6
	VTA-14	-5.1	38.7	595	0.52
	VTA-19	-7.9	36.9	610	1
	VTA-23	-7	37.8	391	0.4
	VTA-24	-7.2	37	587	0.4
	VTA-28	-6	37.7	508	0.4
	VTA-29	-6	37.7	771	0.4
	VTA-34	-5.5	38.8	91	0.4
	VTA-35	-5	38.8	198	0.4
	VTA-36	-5	38.8	288	0.2
	UDZ-03	-7.8	36.9	789	1

Supplementary Information Table S7 | Parameters of the cluster-specific height-diameter allometric models used in for AfriMont plot network. A Weibull model (following ref.[58]) was used.

Cluster	Sites with field height	Heights sampled	Sites without field height	a	b	c
high EA	ABE, KUK, RWE(high)	1690	MAU(high), VRG(high)	1671	0.0019	0.485
high Kilimanjaro	KIL(high)	677		25.949	0.035	1.016
dry EA	KUL, NYI	679		1314	0.0032	0.392
dry WA (& YAY)	BAB,MBA, OKU	1467	NGE, YAY	25.677	0.047	0.926
wet WA	NGI, TNP	331	BAK, NIM, RUM (low)	46.087	0.063	0.659
mid Albertine/EA	BUR,BWI(high), ITO(high), KAH, NYU, RWE(low)	5363	BON, JAB, KAF, MAU (mid), SHE, VRG(low)	30.409	0.025	1.021
low Albertine	BUD, ITO(low), KIB	617	BWI (low), MPG, RAB	99.994	0.023	0.699
Mt Cameroon	CAM	4014	RUM (mid)	28.845	0.03	0.989
mid EAM & Mozambique	KIL(low), TAI, UDZ, USA(mid)	1046	CHI, LIC, MAB, MUL, UKA(mid), ULU(mid)	127.507	0.02	0.592
low EAM	USA(low)	109	GUU, UKA(low), ULU (low)	50.042	0.025	0.96
hyper dry EA	MAR	301	HAR	25.691	0.195	0.493

EA: East Africa, WA: West Africa, EAM: Eastern Arc Mountains, low: low elevations, mid: mid elevations, high: high elevations. For site codes refer to Table S5.

Plots were clustered using selected climatic variables (mean annual temperature, temperature seasonality, total precipitation, precipitation seasonality and minimum temperature). We computed aboveground carbon estimates for sites with field height (H) measurements available, using: a) field-H, b) cluster-specific-H-model and c) all-sites-H-model. For most sites (except two) approach b (cluster-specific-H-model) outperformed approach c (all-sites-H-model), therefore, approach b was used for sites with no field measurements of height.