

Supplementary Materials for

Combating transnational organized crime by linking multiple large ivory seizures to the same dealer

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Published 19 September 2018, *Sci. Adv.* **4**, eaat0625 (2018)
DOI: 10.1126/sciadv.aat0625

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Supplementary Materials

Table S1A. Western forest elephant reference locations.

Country Code	Reference Location	Geographic Region	Latitude	Longitude	Number of Samples
SL	Outamba-Kilimi	Western Forest	9.72	-12.13	8
GN	Ziama Classified Forest	Western Forest	8.28	-9.25	7
CI	Taï	Western Forest	5.8	-7.5	1
BF	Mouhoun Complex	Western Forest	11.6	-3.3	52
GH	Bia	Western Forest	6.33	-3	18
GH	Mole	Western Forest	9	-2	12
BF	Pô-Nazinga-Sissili	Western Forest	11.3	-1.5	6
TG	Fazao-Malfakassa	Western Forest	8.7	0.8	13
BJ/BF	Pendjari-Arli	Western Forest	11.3	1.4	102
BJ/BF	W	Western Forest	11.9	2.4	12

Table S1B. Central forest elephant reference locations.

Country Code	Reference Location	Geographic Region	Latitude	Longitude	Number of Samples
CM	Banyang-Mbo	Central Forest	5	9.5	6
GA	Loango-Moukalaba	Central Forest	-2	9.9	14
GA	Lopé	Central Forest	-0.25	11.53	17
AO	Cabinda Province	Central Forest	-4.7	12.65	3
GA	Minkébé	Central Forest	1.8	12.7	24
CM	Dja	Central Forest	3.2	13	5
GA	Batéké Plateau	Central Forest	-2.2	13.8	12
CM	Nki	Central Forest	2.4	14.5	14
CG	Odzala-Kokoua	Central Forest	1	14.9	37
CF	Dzanga-Sangha	Central Forest	2.8	16.35	94
CF	Bamingui	Central Forest	7.54	20.18	2
CD	Salonga North	Central Forest	-1.21	20.96	23
CD	Salonga South	Central Forest	-2.1	21.1	6
CD	Bomu East	Central Forest	4.46	24.66	12
CD	Lomami	Central Forest	-1.44	24.95	8
SS	Southern	Central Forest	6.6	28.3	1
CD	Okapi	Central Forest	1.5	28.5	10
CD	Kahuzi-Biega	Central Forest	-2.2	28.7	1
CD	Garamba	Central Forest	4	29.46	27
RW	Volcans	Central Forest	-1.5	29.5	9
UG	Bwindi Impenetrable	Central Forest	-1	29.7	4
UG	Semuliki	Central Forest	0.8	30	3
UG	Queen Elizabeth	Central Forest	-0.2	30	1
UG	Kibale	Central Forest	0.5	30.4	9
SS	Bandingilo	Central Forest	4.9	32	1
SS	Kidepo	Central Forest	4.4	32.6	3

Table S1C. Southern savannah elephant reference locations.

Country Code	Reference Location	Geographic Region	Latitude	Longitude	Number of Samples
ZA	Kruger	Southern Savannah	-23.83	31.5	109
BW	Mashatu-Tuli	Southern Savannah	-22.08	29.11	22
NA	Torra Conservancy	Southern Savannah	-20.16	13.59	2
ZW	Hwange	Southern Savannah	-19.05	26.6	54
NA	Etosha	Southern Savannah	-18.75	15.5	14
MZ	Gorongosa	Southern Savannah	-18.55	34.26	13
BW	Chobe	Southern Savannah	-18.33	24.86	81
ZW	Sengwa Landscape	Southern Savannah	-18.22	28.56	16
MW	Majete	Southern Savannah	-16	34.7	8
ZM	Lower Zambezi	Southern Savannah	-15.5	29.7	10
ZM	Kafue	Southern Savannah	-15.2	25.9	18
MW	Liwonde	Southern Savannah	-14.9	35	17
MW	Kasungu	Southern Savannah	-12.9	33.5	12
ZM	Kasanka	Southern Savannah	-12.6	30.2	3
ZM	Luangwa	Southern Savannah	-12.5	32	26
MZ	Niassa	Southern Savannah	-11.83	37.91	26
ZM	Sumbu	Southern Savannah	-8.63	30.43	7

Table S1D. Eastern savannah elephant reference locations.

Country Code	Reference Location	Geographic Region	Latitude	Longitude	Number of Samples
TZ	Selous Ecosystem	Eastern Savannah	-8.8	37.5	18
TZ	Udzungwa Mountains	Eastern Savannah	-7.75	36.69	5
TZ	Mikumi	Eastern Savannah	-7.6	37.14	59
TZ	Ruaha	Eastern Savannah	-7.5	34.75	35
TZ	Rukwa	Eastern Savannah	-7.2	31.98	12
TZ	Katavi	Eastern Savannah	-6.74	31.05	18
TZ	Saadani	Eastern Savannah	-5.98	38.69	1
TZ	Muhesi	Eastern Savannah	-5.67	34.58	19
KE	Shimba Hills	Eastern Savannah	-4.3	39.4	39
TZ	Tarangire	Eastern Savannah	-4.1	36.1	39
TZ	Ngorongoro	Eastern Savannah	-3.23	35.57	15
KE	Tsavo	Eastern Savannah	-3.01	38.51	73
KE	Amboseli	Eastern Savannah	-2.55	37.26	70
RW	Nyungwe Forest	Eastern Savannah	-2.5	29.3	2
TZ	Serengeti	Eastern Savannah	-1.97	35.03	16
RW	Akagera	Eastern Savannah	-1.6	30.7	8
KE	Masai Mara	Eastern Savannah	-1.4	35.3	10
CD	Virunga	Eastern Savannah	-1.25	29.5	9
KE	Aberdare	Eastern Savannah	-0.42	36.63	25
UG	Queen Elizabeth	Eastern Savannah	-0.2	30.11	63
KE	Mount Kenya	Eastern Savannah	-0.15	37.3	31
KE/UG	Mount Elgon	Eastern Savannah	0.5	34.62	1
KE	Marsabit	Eastern Savannah	2.3	37.9	4
UG	Murchison Falls	Eastern Savannah	2.33	31.54	36
SS	Nimule	Eastern Savannah	3.6	32	31
UG	Kidepo Valley	Eastern Savannah	3.84	33.69	17
SS	Bandingilo	Eastern Savannah	4.91	32	2
ET	Mago	Eastern Savannah	5.5	36.3	4
SS	Boma	Eastern Savannah	6.6	33.8	11
SS	Ez Zeraf	Eastern Savannah	7.8	30.7	30
ER	Gash-Setit	Eastern Savannah	14.8	37.3	3
UG	Kibale	Eastern Savannah	0.5	30.5	23

Table S1E. Northern savannah elephant reference locations.

Country Code	Reference Location	Geographic Region	Latitude	Longitude	Number of Samples
TD	Larmanaye Ecosystem	Northern Savannah	8	16	8
CM	Benoué	Northern Savannah	8.1	14	16
NG	Yankari	Northern Savannah	9.83	10.58	3
TD	Massenya Ecosystem	Northern Savannah	10.45	16.48	8
TD	Zakouma	Northern Savannah	11.1	19.5	29
CM	Waza	Northern Savannah	11.3	14.8	20
ML	Gourma Partial	Northern Savannah	15.5	-2.4	34

Country code: ISO Alpha-2

Reference Location: Name of reference population locations

Latitude and Longitude: Decimal degrees

Table S2A. Seizures 2002-2012.

Location of Seizure	Month/Year of Seizure	Weight (tonne)	Known Point(s) of Export	S_Z	E_x	A_M	S	F	H
Singapore	Jun 2002	6.5	Malawi	532	66	38	35	0	0
Hong Kong	May 2006	4.0	Douala	603	99	32	0	29	0
Taiwan	Jul 2006	3.0	DSM	744	60	48	30	0	0
Taiwan	Jul 2006	1.2	DSM	350	89	55	40	0	0
Hong Kong	Jul 2006	2.6	DSM	390	150	114	96	0	0
Singapore	Mar 2007	0.5	Zambia	70	45	37	29	0	0
Phillippines	Mar 2009	4.8	DSM	1701	281	106	99	0	0
Vietnam	Apr 2010	2.2	Mombasa	400	100	99	86	0	0
Kenya	Aug 2010	1.5	Nairobi	317	219	126	116	0	0
Thailand	Jan 2011	0.3	MOZ	69	73	45	32	0	0
Kenya	May 2011	1.3	Nairobi	115	77	41	39	0	0
Kenya	Sep 2011	0.3	Mombasa	32	19	14	14	0	0
Malaysia	Sep 2011	1.1	UNK	545	82	68	66	0	0
Kenya	Dec 2011	1.5	Mombasa	470	184	164	141	0	0
Sri Lanka	May 2012	1.5	Entebbe, Mombasa	359	205	130	126	0	0
Hong Kong	Oct 2012	1.9	DSM	972	122	83	67	0	0
Hong Kong	Oct 2012	1.9	Mombasa	237	100	88	74	0	0
Hong Kong	Jan 2013	1.3	Mombasa	779	106	51	43	0	0
Malaysia	Dec 2012	6.0	Lome, Mombasa	2300	266	207	117	75	0

Table S2B. Seizures 2013-2016.

Location of Seizure	Month/Year of Seizure	Weight (tonne)	Known Point(s) of Export	S _Z	E _x	A _M	S	F	H
Kenya	Jan 2013	3.8	Mombasa	638	184	164	144	1	1
Malawi	May 2013	2.6	Malawi	781	200	62	60	0	0
Dubai	May 2013	1.5	Entebbe, Mombasa	259	151	119	100	0	0
Kenya	Jun 2013	3.3	Mombasa	444	187	148	130	0	0
Kenya	Jun 2013	1.5	Entebbe, Mombasa	775	348	279	218	12	11
Hong Kong	Jul 2013	2.0	Lome	1148	200	49	0	48	0
Togo	Aug 2013	0.7	Lome	69	69	36	2	23	1
Hong Kong	Aug 2013	2.2	Lagos	1120	200	119	4	84	0
Uganda	Oct 2013	2.9	Entebbe	823	187	116	94	4	3
Kenya	Oct 2013	2.9	Entebbe, Mombasa	956	185	155	129	4	2
Kenya	Oct 2013	2.0	Mombasa	686	185	163	134	0	0
Uganda	Dec 2013	1.4	Entebbe	440	188	106	93	5	0
Togo	Jan 2014	3.9	Lome	1500	200	79	6	70	0
Singapore	Mar 2014	1.0	Entebbe, Mombasa	-	53	36	34	0	1
Uganda	May 2014	1.8	Entebbe	381	148	120	86	1	3
Kenya	Jun 2014	2.2	Mombasa	314	195	154	112	0	0
Uganda	Jul 2014	0.6	Entebbe	271	98	81	52	0	0
Singapore	May 2015	4.6	Mombasa	1161	250	195	181	2	0
Mozambique	May 2016	1.5	Matola	356	50	50	48	0	0
South Sudan	Jun 2016	0.5	Entebbe	82	82	64	56	1	1

DSM: Dar es Salaam

MOZ: Mozambique

UNK: unknown

S_Z: Number of tusks in seizureE_x: Number of tusks extractedA_M: Number of tusks amplified at ≥ 10 loci

S: Number of unique savannah elephant genotypes

F: Number of unique forest elephant genotypes

H: Number of unique hybrid elephant genotypes

Table S3A. Matching pairs of savannah elephant samples.

Sample 1	Sample 2	M	D	U	Seizure 1	Seizure 2
AVP.EBB 154	KKP015	16	0	0	Uganda Oct 2013 2.9t	Kenya Jun 2013 1.5t
AVP.EBB 239	KKP009	16	0	0	Uganda Oct 2013 2.9t	Kenya Jun 2013 1.5t
AVP.EBB 391	KKP347	16	0	0	Uganda Oct 2013 2.9t	Kenya Jun 2013 1.5t
DUB030	KSP046	15	1	0	Dubai May 2013 1.5t	Kenya Jan 2013 3.8t
DUB060	KCM045	10	0	6	Dubai May 2013 1.5t	Kenya Oct 2013 2.9t
DUB065	KSP139	16	0	0	Dubai May 2013 1.5t	Kenya Jan 2013 3.8t
DUB141	KCM026	16	0	0	Dubai May 2013 1.5t	Kenya Oct 2013 2.9t
DUB142	KCM019	15	1	0	Dubai May 2013 1.5t	Kenya Oct 2013 2.9t
KAD06	KSP001	14	1	1	Kenya Sep 2011 0.3t	Kenya Jan 2013 3.8t
KCM054	KX093	10	2	4	Kenya Oct 2013 2.9t	Kenya Oct 2013 2.0t
KCM111	KX038	12	3	1	Kenya Oct 2013 2.9t	Kenya Oct 2013 2.0t
KCM118	KX100	14	1	1	Kenya Oct 2013 2.9t	Kenya Oct 2013 2.0t
KCM140	MYS1916	14	0	2	Kenya Oct 2013 2.9t	Malaysia Dec 2012 6.0t
KCM160	UG.B137	14	2	0	Kenya Oct 2013 2.9t	Uganda May 2014 1.8t
KCM168	UG.B131	15	1	0	Kenya Oct 2013 2.9t	Uganda May 2014 1.8t
KCM170	KX130	16	0	0	Kenya Oct 2013 2.9t	Kenya Oct 2013 2.0t
KKP147	UWA.A 040	16	0	0	Kenya Jun 2013 1.5t	Uganda Dec 2013 1.4t
KKP323	UWA.B 100	16	0	0	Kenya Jun 2013 1.5t	Uganda Dec 2013 1.4t
KMN004	SL324	15	1	0	Kenya Dec 2011 1.5t	Sri Lanka May 2012 1.5t
MYS0012	TOGI030	16	0	0	Malaysia Dec 2012 6.0t	Togo Jan 2014 3.9t
MYS0062	TOGI176	11	0	5	Malaysia Dec 2012 6.0t	Togo Jan 2014 3.9t
MYS1119	SL129	16	0	0	Malaysia Dec 2012 6.0t	Sri Lanka May 2012 1.5t

Table S3B. Matching pairs of forest and hybrid elephant samples.

Sample 1	Sample 2	Spp.	M	D	U	Seizure 1	Seizure 2
G04	KKP021-123	F	14	1	0	Garamba Poaching Event DRC May 2012 (22 elephants killed)	Kenya Jun 2013 1.5t
G05	KKP020	F	14	1	0	Garamba Poaching Event DRC May 2012 (22 elephants killed)	Kenya Jun 2013 1.5t
G09	KKP140	H	15	0	0	Garamba Poaching Event DRC May 2012 (22 elephants killed)	Kenya Jun 2013 1.5t
G15	KKP118	F	15	0	0	Garamba Poaching Event DRC May 2012 (22 elephants killed)	Kenya Jun 2013 1.5t
MYS0648	TG59	F	14	0	1	Malaysia Dec 2012 6.0t	Togo Aug 2013 0.7t

M: Matching loci
D: Discrepant loci
U: Unconfirmed loci
Spp.: Species
S: Savannah elephant
F: Forest elephant
H: Hybrid elephant
t: tonne (metric ton)

Table S4. Dropout model parameters.

Locus	Forest $\beta_{0,l}$	Forest $\beta_{1,l}$	Savannah $\beta_{0,l}$	Savannah $\beta_{1,l}$
FH67	20.90762	-2.337118	22.52742	-2.48681
FH71	16.6655	-1.892238	18.56313	-2.04957
FH19	20.96454	-2.248918	19.49798	-2.110348
FH129	26.03334	-2.845293	18.95384	-2.090801
FH60	20.43614	-2.309053	21.41919	-2.362466
FH127	26.94547	-2.914146	23.83428	-2.546739
FH126	20.17681	-2.298858	21.76632	-2.439058
FH153	N/A	N/A	23.0354	-2.517223
FH94	24.38787	-2.581312	20.41949	-2.225514
FH48	21.75029	-2.346354	23.47679	-2.537773
FH40	24.18229	-2.58625	24.77487	-2.610052
FH39	25.33755	-2.712232	24.83543	-2.666695
FH103	20.31656	-2.268773	24.07823	-2.605241
FH102	22.23563	-2.448915	22.70349	-2.453062
S03	20.37575	-2.252319	21.56734	-2.3314
S04	18.88276	-2.134013	24.23833	-2.631552

Beta coefficients $\beta_{0,l}$ and $\beta_{1,l}$ determined by maximum likelihood and used in the fitted model of drop-out probabilities (see methods). These are calculated separately for forest and savanna elephants.

Table S5. Estimated total number of matching samples (M_{ij}) for each seizure pair.

Seizure i	Seizure j	m_{ij}	n_i	n_j	N_i	N_j	M_j	$M_{ij}/\min(N_i N_j)$
Kenya Sep 2011 0.3t	Kenya Jan 2013 3.8t	1	14	144	32	638	2	0.0625
Sri Lanka May 2012 1.5t	Kenya Dec 2011 1.5t	1	126	141	359	470	2	0.0056
Kenya Oct 2013 2.9t	Malaysia Dec 2012 6.0t	1	129	117	956	2300	8	0.0084
Dubai May 2013 1.5t	Kenya Jan 2013 3.8t	2	100	144	259	638	5	0.0193
Kenya Jun 2013 1.5 t	Uganda Oct 2013 2.9t	3	218	94	775	823	24	0.0310
Togo Aug 2013 0.7t	Malaysia Dec 2012 6.0t	1	23	75	69	2300	3	0.0435
Dubai May 2013 1.5t	Kenya Oct 2013 2.9t	2	100	129	259	956	5	0.0193
Kenya Oct 2013 2.0t	Kenya Oct 2013 2.9t	4	134	129	686	956	21	0.0306
Uganda Dec 2013 1.4t	Kenya Jun 2013 1.5t	2	93	218	440	775	9	0.0205
Togo 2014 3.9t	Malaysia Dec 2012 6.0t	2	6	117	1500	2300	500	0.3333
Uganda May 2014 1.8t	Kenya Oct 2013 2.9t		86	129	381	956	8	0.0210
Sri Lanka May 2012 1.5t	Malaysia Dec 2012 6.0t	1	126	117	359	2300	3	0.0084

t: tonne (metric ton)

m_{ij} : observed number of matching samples between seizures i and j

n_i : number of unique genotypes in seizure i

n_j : number of unique genotypes in seizure j

N_i : total number of samples in seizure i

N_j : total number of samples in seizure j

M_{ij} : Estimated total number of matching samples between seizures i and j

$M_{ij}/\min(N_i N_j)$: Fraction of matching samples in the smaller of seizures i and j

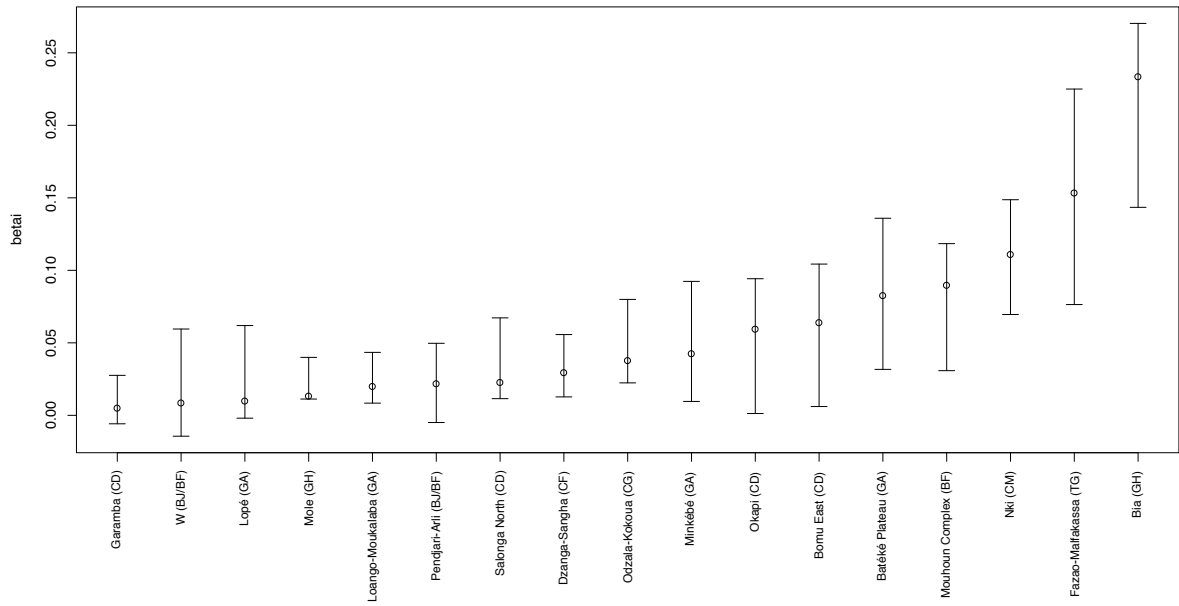


Fig. S1. Population-specific F_{ST} estimates for forest elephants.

Point estimates: circles

Whiskers: 95% confidence intervals from bootstrapping over loci

Mean point estimate: $\theta = 0.059$

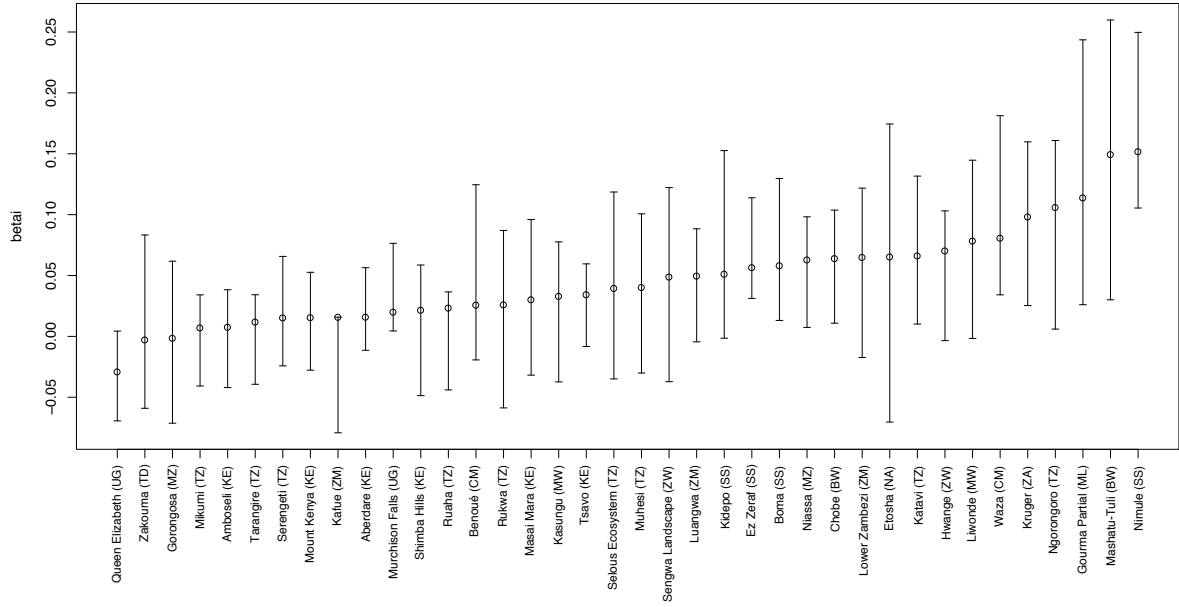


Fig. S2. Population-specific F_{ST} estimates for savannah elephants.

Point estimates: circles

Whiskers: 95% confidence intervals from bootstrapping over loci

Mean point estimate: $\theta = 0.047$