

Patrick Gonzalez, Compton J. Tucker, and Hamady Sy. 2012. Tree density and species decline in the African Sahel attributable to climate. *Journal of Arid Environments* 78: 55-64.

Appendix. Supplementary data

Table A1. Tree and shrub species, families, and ecological zones, according to published floras (Arbonnier, 2002; Aubréville, 1950; von Maydell, 1990) and observed characteristics.

Species	Family	Ecological zone
<i>Acacia albida</i>	Mimosaceae	Sudan
<i>Acacia ataxacantha</i>	Mimosaceae	Sudan
<i>Acacia ehrenbergiana</i>	Mimosaceae	Sahel
<i>Acacia gourmanensis</i>	Mimosaceae	Guinea
<i>Acacia laeta</i>	Mimosaceae	Sahel
<i>Acacia macrostachya</i>	Mimosaceae	Sudan
<i>Acacia nilotica adansonii</i>	Mimosaceae	Sahel
<i>Acacia nilotica tomentosa</i>	Mimosaceae	Sahel
<i>Acacia pennata</i>	Mimosaceae	Sudan
<i>Acacia polyacantha</i>	Mimosaceae	Guinea
<i>Acacia raddiana</i>	Mimosaceae	Sahel
<i>Acacia senegal</i>	Mimosaceae	Sahel
<i>Acacia seyal</i>	Mimosaceae	Sahel
<i>Acacia sieberiana</i>	Mimosaceae	Guinea
<i>Adansonia digitata</i>	Bombacaceae	Sudan
<i>Adenium obesum</i>	Apocynaceae	Sudan
<i>Annona glauca</i>	Annonaceae	Guinea
<i>Annona senegalensis</i>	Annonaceae	Guinea
<i>Anogeissus leiocarpus</i>	Combretaceae	Guinea
<i>Balanites aegyptiaca</i>	Balanitaceae	Sahel
<i>Bauhinia rufescens</i>	Caesalpiniaceae	Sudan
<i>Bombax costatum</i>	Bombacaceae	Guinea
<i>Borassus aethiopicum</i>	Arecaceae	Sudan
<i>Boscia salicifolia</i>	Capparidaceae	Sudan

Species	Family	Ecological zone
<i>Boscia senegalensis</i>	Capparaceae	Sahel
<i>Butyrospermum parkii</i>	Sapotaceae	Sudan
<i>Cadaba farinosa</i>	Capparaceae	Sahel
<i>Cadaba glandulosa</i>	Capparaceae	Sahel
<i>Calotropis procera</i>	Asclepiadaceae	Sahel
<i>Capparis corymbosa</i>	Capparaceae	Sahel
<i>Capparis decidua</i>	Capparaceae	Sahel
<i>Capparis tomentosa</i>	Capparidaceae	Sudan
<i>Cassia occidentalis</i>	Caesalpiniaceae	Sudan
<i>Cassia sieberiana</i>	Caesalpiniaceae	Guinea
<i>Celtis integrifolia</i>	Ulmaceae	Guinea
<i>Combretum aculeatum</i>	Combretaceae	Sahel
<i>Combretum glutinosum</i>	Combretaceae	Sudan
<i>Combretum micranthum</i>	Combretaceae	Sudan
<i>Combretum nigricans</i>	Combretaceae	Guinea
<i>Commiphora africana</i>	Burseraceae	Sahel
<i>Crataeva adansonii</i>	Capparidaceae	Guinea
<i>Dalbergia melanoxylon</i>	Fabaceae	Sudan
<i>Detarium microcarpum</i>	Caesalpiniaceae	Guinea
<i>Dichrostachys cinerea</i>	Mimosaceae	Sudan
<i>Diospyros mespiliformis</i>	Ebenaceae	Guinea
<i>Ekebergia senegalensis</i>	Meliaceae	Guinea
<i>Entada africana</i>	Mimosaceae	Guinea
<i>Euphorbia balsamifera</i>	Euphorbiaceae	Sahel
<i>Feretia apodanthera</i>	Rubiaceae	Sudan
<i>Ficus gnaphalocarpa</i>	Moraceae	Guinea
<i>Ficus ingens</i>	Moraceae	Sahel
<i>Ficus iteophylla</i>	Moraceae	Sudan
<i>Ficus platyphylla</i>	Moraceae	Guinea
<i>Ficus polita</i>	Moraceae	Guinea
<i>Ficus thonningii</i>	Moraceae	Guinea
<i>Gardenia ternifolia</i>	Rubiaceae	Sudan
<i>Grewia bicolor</i>	Tiliaceae	Sahel
<i>Grewia flavescens</i>	Tiliaceae	Sahel
<i>Grewia tenax</i>	Tiliaceae	Sahel

Species	Family	Ecological zone
<i>Grewia villosa</i>	Tiliaceae	Sahel
<i>Guiera senegalensis</i>	Combretaceae	Sudan
<i>Heeria insignis</i>	Anacardiaceae	Guinea
<i>Hyphaene thebiaca</i>	Arecaceae	Sahel
<i>Jatropha chevalieri</i>	Euphorbiaceae	Sudan
<i>Jatropha curcas</i>	Euphorbiaceae	Sudan
<i>Khaya senegalensis</i>	Meliaceae	Guinea
<i>Lannea acida</i>	Anacardiaceae	Guinea
<i>Lannea microcarpa</i>	Anacardiaceae	Sudan
<i>Lannea velutina</i>	Anacardiaceae	Guinea
<i>Leptadenia pyrotechnica</i>	Asclepiadaceae	Sahel
<i>Maerua crassifolia</i>	Capparaceae	Sahel
<i>Maerua oblongifolia</i>	Capparaceae	Sudan
<i>Mangifera indica</i>	Anacardiaceae	Sudan
<i>Mitragyna inermis</i>	Rubiaceae	Sudan
<i>Moringa oleifera</i>	Moringaceae	Sudan
<i>Opuntia linguiformis</i>	Cactaceae	Sudan
<i>Parinari marophylla</i>	Rosaceae	Sudan
<i>Parkia biglobosa</i>	Mimosaceae	Guinea
<i>Phoenix dactylifera</i>	Arecaceae	Sahel
<i>Piliostigma reticulatum</i>	Caesalpiniaceae	Sudan
<i>Prosopis africana</i>	Mimosaceae	Guinea
<i>Pterocarpus erinaceus</i>	Fabaceae	Guinea
<i>Pterocarpus lucens</i>	Fabaceae	Sudan
<i>Rhus oxyacantha</i>	Anacardiaceae	Sahel
<i>Salix coluteoides</i>	Salicaceae	Guinea
<i>Salvadora persica</i>	Salvadoraceae	Sahel
<i>Sclerocarya birrea</i>	Anacardiaceae	Sudan
<i>Securidaca longipedunculata</i>	Polygalaceae	Guinea
<i>Securinega virosa</i>	Euphorbiaceae	Sudan
<i>Sterculia setigera</i>	Sterculiaceae	Sudan
<i>Stereospermum kunthianum</i>	Bignoniaceae	Sudan
<i>Strychnos spinosa</i>	Loganiaceae	Guinea
<i>Tamarindus indica</i>	Caesalpiniaceae	Sudan
<i>Terminalia avicennioides</i>	Combretaceae	Sudan

Species	Family	Ecological zone
<i>Terminalia macroptera</i>	Combretaceae	Guinea
unknown [atuko, aborko (Arabe du Tchad)]		Guinea
unknown [capsaabi (Pulaar)]		Sudan
unknown [fugaa-fugaa (Bambara)]		Sudan
unknown [hano (Zarma)]		Sahel
unknown [jukomomi (Buduma)]		Sahel
unknown [kabule (Buduma)]		Guinea
unknown [kormut (Arabe du Tchad)]		Sahel
unknown [krerege (Buduma)]		Sudan
unknown [maji (Zarma)]		Sudan
unknown [markoko (Buduma)]		Sudan
unknown [ngelgoti, tu tullu (Pulaar)]		Sahel
unknown [nzanaa (Bambara)]		Guinea
unknown [regewi (Pulaar)]		Sahel
unknown [rini, sisi (Zarma)]		Guinea
unknown [runhu (Zarma)]		Guinea
unknown [wenegama (Zarma)]		Sudan
<i>Vitex doniana</i>	Verbenaceae	Guinea
<i>Ximenia americana</i>	Olacaceae	Guinea
<i>Zizyphus mauritiana</i>	Rhamnaceae	Sahel
<i>Zizyphus mucronata</i>	Rhamnaceae	Sudan
<i>Zizyphus spina-christi</i>	Rhamnaceae	Sudan

Table A2. Thresholds for detecting trees of $h \geq 3$ m in aerial photos and Ikonos images (mean \pm 95% confidence interval [CI]). Gray scale: black = 0%, white = 100%.

		Tree center darkness		Crown area		Contrast between tree and surroundings		<i>n</i>
		mean	mini- mum	mean	mini- mum	mean	mini- mum	
		(gray %)		(m ²)		(gray %)		
Njóobéen Mbataar	1954	21 \pm 2	13	23 \pm 3	13	20 \pm 2	9	41
	1989	40 \pm 3	25	21 \pm 3	12	23 \pm 2	13	30
	2002	2 \pm 2	0	34 \pm 14	9	84 \pm 6	40	32
Fete	1954	20 \pm 1	11	30 \pm 3	14	24 \pm 2	11	55
	2002	2 \pm 1	0	15 \pm 2	7	41 \pm 2	19	65
Wolum	1954	16 \pm 4	8	28 \pm 6	22	39 \pm 9	23	10
	2002	3 \pm 3	0	45 \pm 20	20	59 \pm 7	25	19

Table A3. Comparison of trees in field quadrats with trees in the Ikonos images to calibrate tree data from the Ikonos images.

	Trees ($h \geq 3$ m) in field quadrats	Trees ($h \geq 3$ m) in Ikonos images	Trees ($h < 3$ m) in Ikonos images	Fraction of field trees visible in Ikonos images
Njóobéen Mbataar	38	32	0	0.84
Fété Olé	84	62	3	0.77
Wolum	1	1	0	1.000
All	123	95	3	0.80

Table A4. Tree density changes (mean \pm 95% CI). See Figure 2 in the main text for tree densities and significance of changes.

Research area	Time period	Area of decrease	Tree mortality (decade ⁻¹)	Tree density change		<i>n</i>
		(fraction of samples)		(fraction of trees)	(decade ⁻¹)	
Njóobéen Mbataar	1954-1989	0.53	0.21 \pm 0.01	-0.22 \pm 0.12	-0.06 \pm 0.03	204
Njóobéen Mbataar	1989-2002	0.43	0.33 \pm 0.04	0.04 \pm 0.12	0.03 \pm 0.09	204
Njóobéen Mbataar	1954-2002	0.56	0.17 \pm 0.01	-0.18 \pm 0.14	-0.04 \pm 0.03	204
Fété Olé	1954-2002	0.59	0.19 \pm 0.004	-0.17 \pm 0.13	-0.03 \pm 0.03	186
Wolum	1954-2002	0.37	0.11 \pm 0.01	0.03 \pm 0.35	0.006 \pm 0.07	202

Table A5. Tree species richness and change by research village area, listed from west to east.

Village	Country	Species richness		Tree species richness change	
		1960	2000	1960-2000	
		(species)		(fraction of species)	(decade ⁻¹)
Juude Waalo	Mauritania	58	24	-0.59	-0.15
Aten	Mauritania	43	26	-0.40	-0.10
Fabugu	Mali	55	55	0	0
Nampabuum	Burkina Faso	46	42	-0.09	-0.02
Banizumbi	Niger	49	29	-0.41	-0.10
Tamaka	Niger	60	39	-0.35	-0.09
Dan Tsuntsu	Niger	55	43	-0.22	-0.05
Guidimouni	Niger	62	59	-0.05	-0.01
Kaylaroom	Chad	21	21	0	0
Buurtey Ganuun	Chad	30	26	-0.13	-0.03
Marchuut	Chad	48	47	-0.02	-0.01
Akar	Chad	38	20	-0.47	-0.12
Kardofal	Chad	46	43	-0.07	-0.002
Ningelin	Chad	46	41	-0.11	-0.003

Table A6. Canonical correlations analyses results. Bold type denotes factors with highest rotated loadings for each canonical function.

	Canonical Function 1			Canonical Function 2		
	rotated loading	loading	<i>P</i>	rotated loading	loading	<i>P</i>
Njóobéen Mbataar (<i>n</i> = 200)						
temperature	-0.89	-0.85	<0.0001	-0.02	0.25	0.0003
precipitation	0.79	0.70	<0.0001	-0.20	-0.43	<0.0001
population	-0.10	0.21	0.003	0.995	0.98	<0.0001
Fete Olé (<i>n</i> = 182)						
temperature	0.70	0.58	<0.0001	-0.05	-0.38	<0.0001
precipitation	-0.14	0.20	0.006	0.67	0.65	<0.0001
soil organic carbon	-0.07	0.10	0.19	0.32	0.31	<0.0001
population	0.68	0.41	<0.0001	-0.37	-0.65	<0.0001
Wolum (<i>n</i> = 198)						
temperature	0.83	0.77	<0.0001	-0.01	-0.31	<0.0001
precipitation	0.62	0.56	<0.0001	-0.07	-0.29	<0.0001
soil organic carbon	-0.40	-0.05	0.46	0.87	0.96	<0.0001
population	-0.06	-0.17	0.02	-0.31	-0.27	0.0001
Sahel Villages (<i>n</i> = 14)						
temperature	0.94	0.71	0.004	-0.14	0.63	0.02
precipitation	-0.73	-0.66	0.01	-0.09	-0.32	0.26
soil organic carbon	0.40	-0.11	0.70	-0.81	0.90	<0.0001
population	0.34	0.62	0.02	0.60	-0.32	0.26

Figure A1.

Njóobéen Mbataar aerial photos, Ikonos images, tree density, and change in tree density.

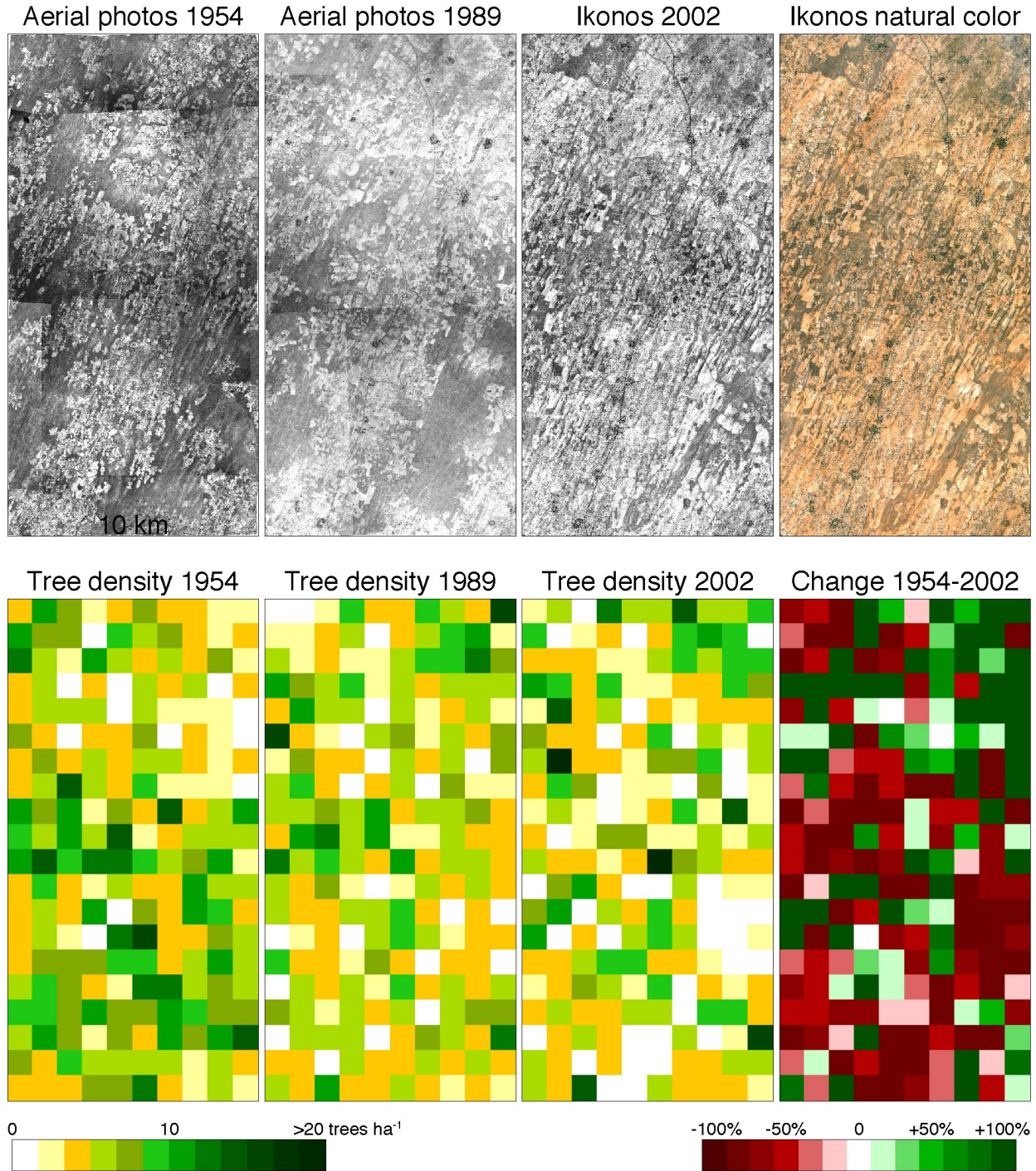


Figure A2.
Fété Olé aerial photos, Ikonos images, tree density, and change in tree density.

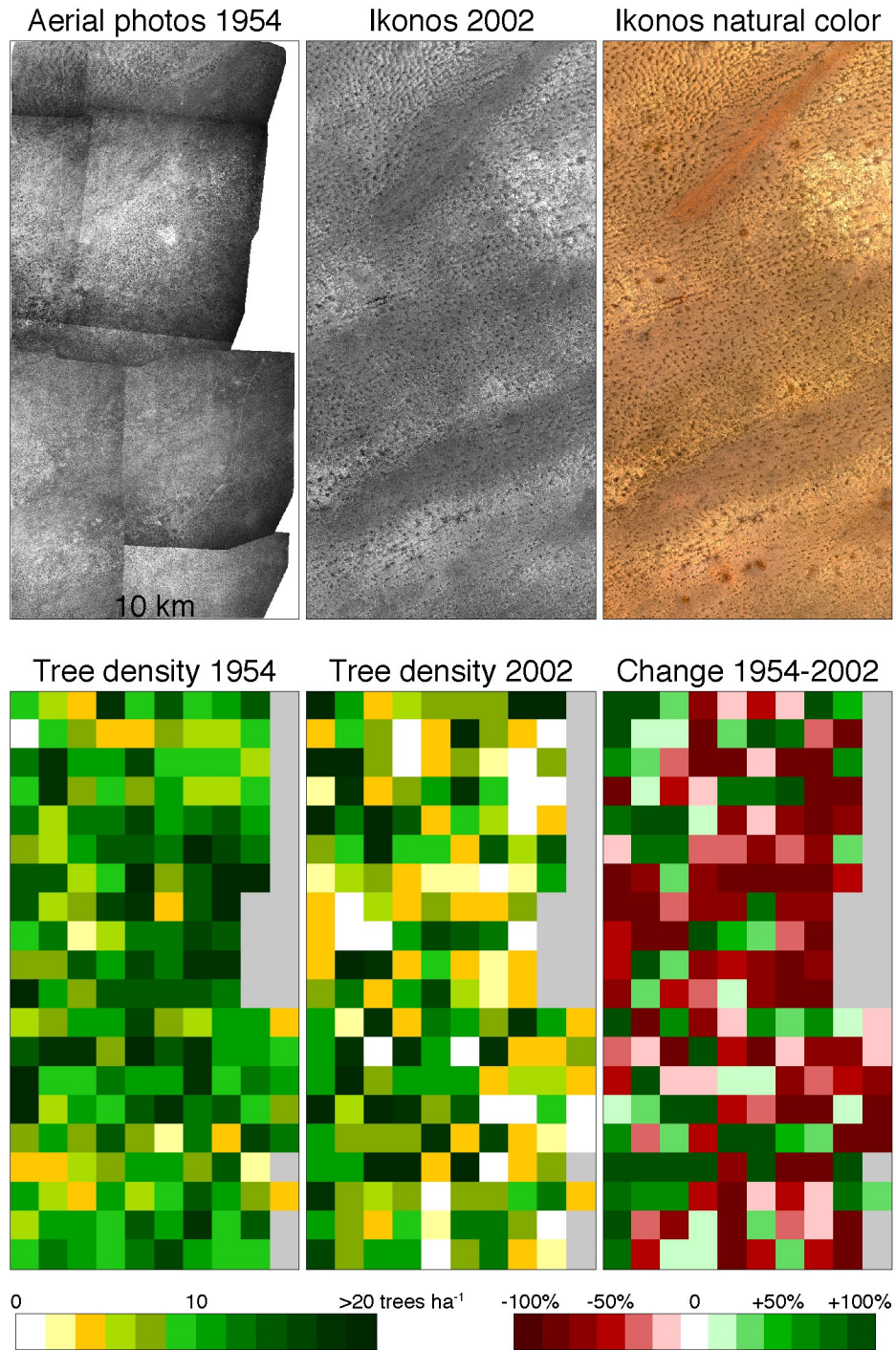
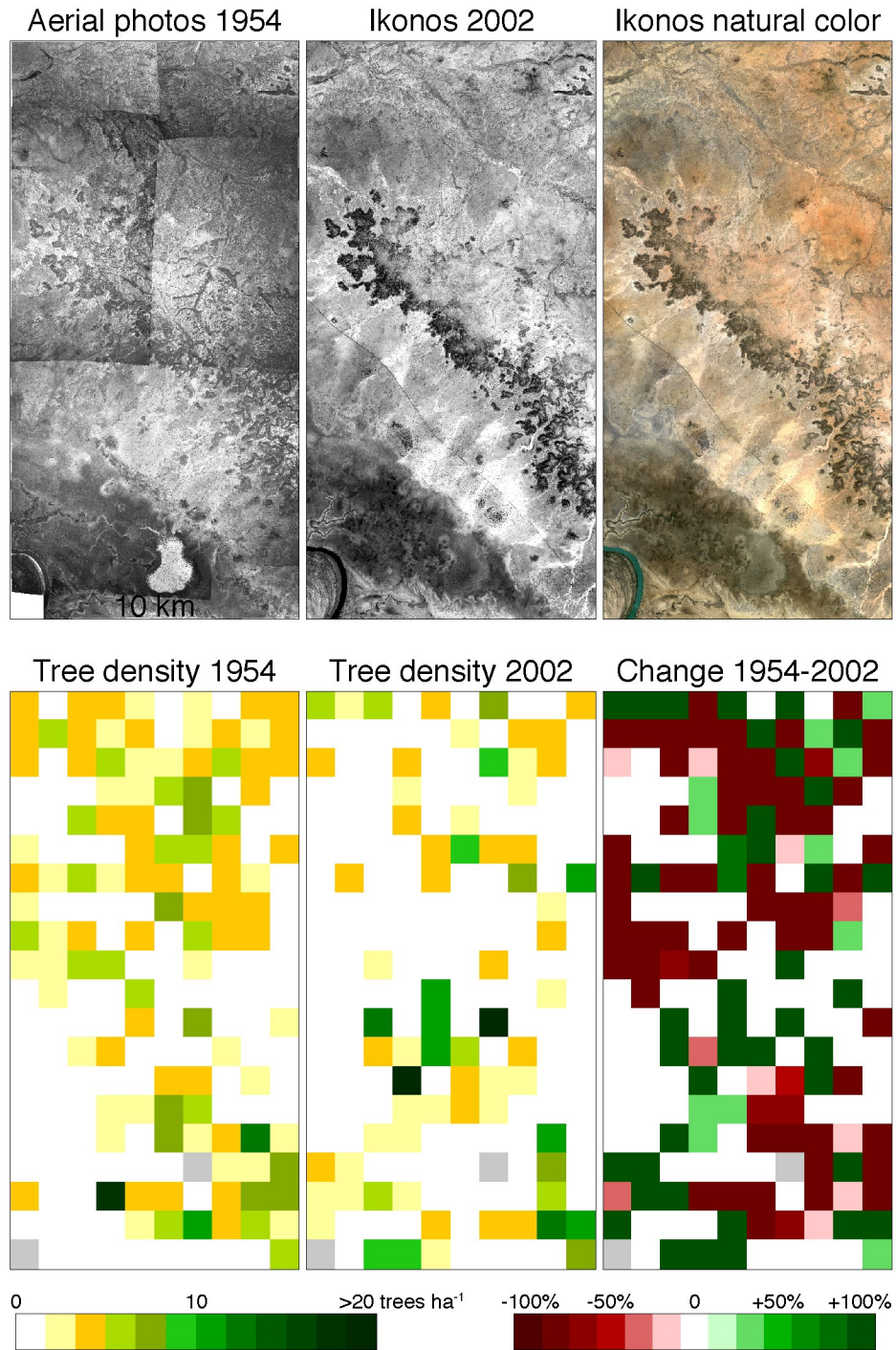


Figure A3.
Wolum aerial photos, Ikonos images, tree density, and change in tree density.



References

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