Supplementary Materials for

The Biological Underpinnings of Namib Desert Fairy Circles

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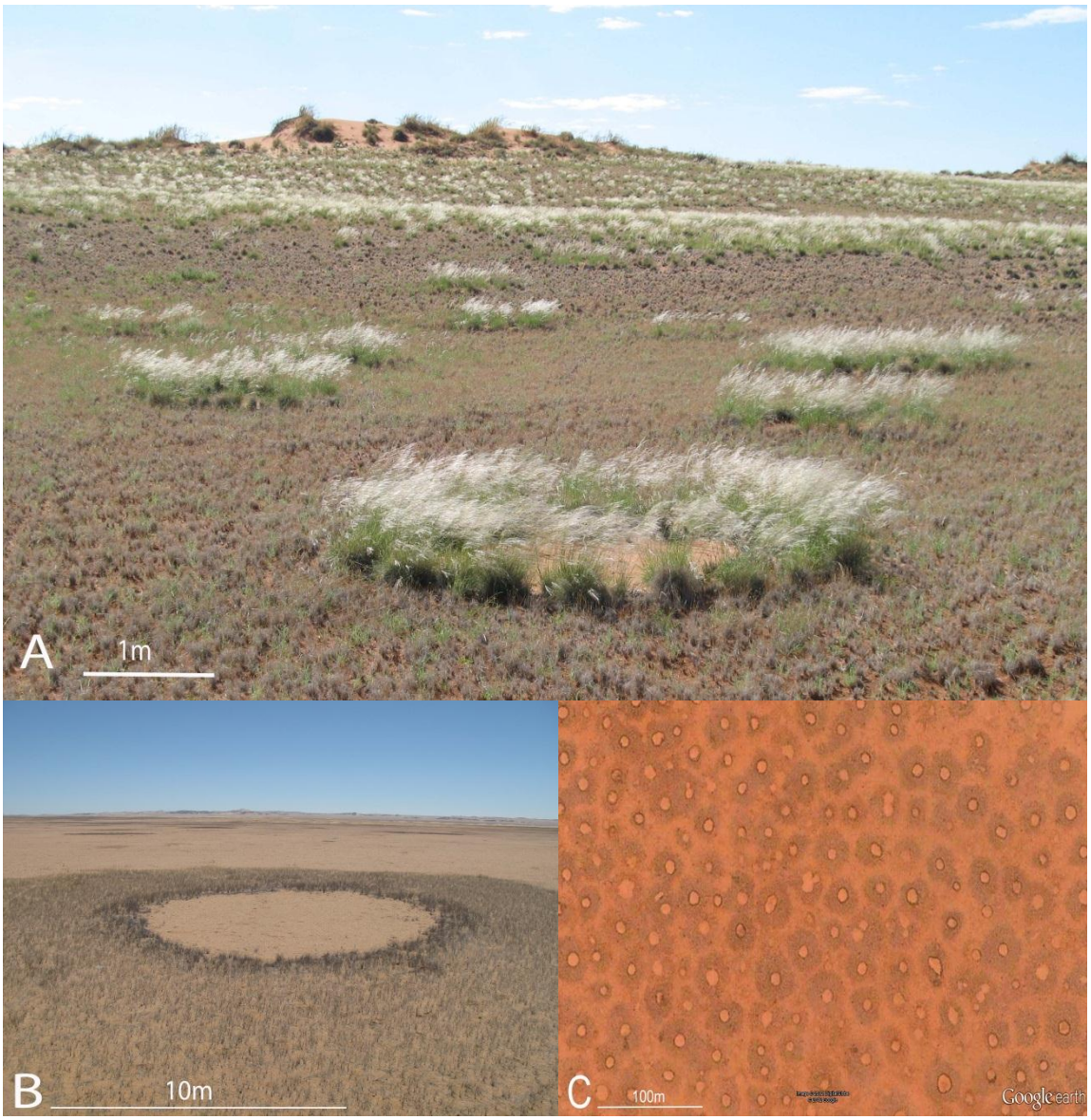

Fig. S1A: Fairy circles (FCs) with a the central “bare patch”, surrounded by a well developed “perennial belt” within a short-lived grassland matrix at Dieprivier, Namibia. S1B: On shallow soils an additional broader “halo” of long-lived grass can develop outside the “perennial belt” (Hartmannberge, Namibia). S1C: Neighboring halos sometimes form a continuous mosaic of halos (Hartmannberge, Namibia).

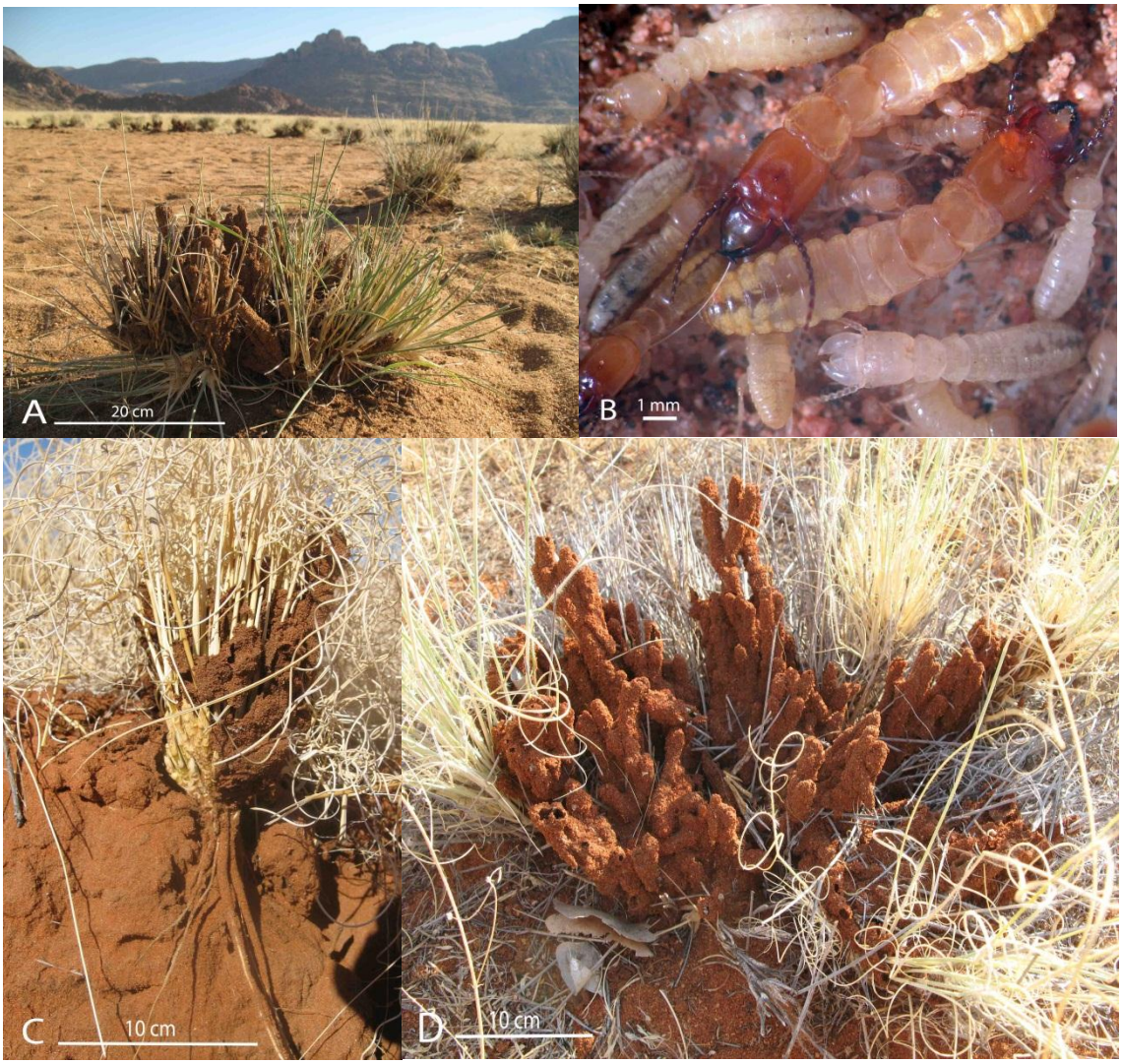

Fig. S2A, C, D: Sheetings, formed by *Psammotermes allocerus* covering *Stipagrostis giessii* plants at Marienfluss valley, Namibia. S5B: *Psammotermes allocerus* workers and soldiers.

FC morphology is related to latitude. The morphological measures of FCs, especially their diameter, is positively correlated with aridity and negatively correlated with latitude. Mean diameter (based on measurement of 50 FCs / hotspot) of the bare patch increases from 3.71 m in the South (Numees, South Africa) to 34.67 m in the North (Chamune/Chimalavera, Angola) (Fig. S3), accompanied by a decrease of density of FCs/area from 6/ha in the North (Chamune/Chimalavera) to 56/ha in the South (Wolwedans, Namibia) (Fig. S4). As a combination of both parameters, the cumulative surface area of all bare patches increases from 0.8 % in the South (Numees) to 55.7 % in the North (Chamune/Chimalavera) (Fig. S5).

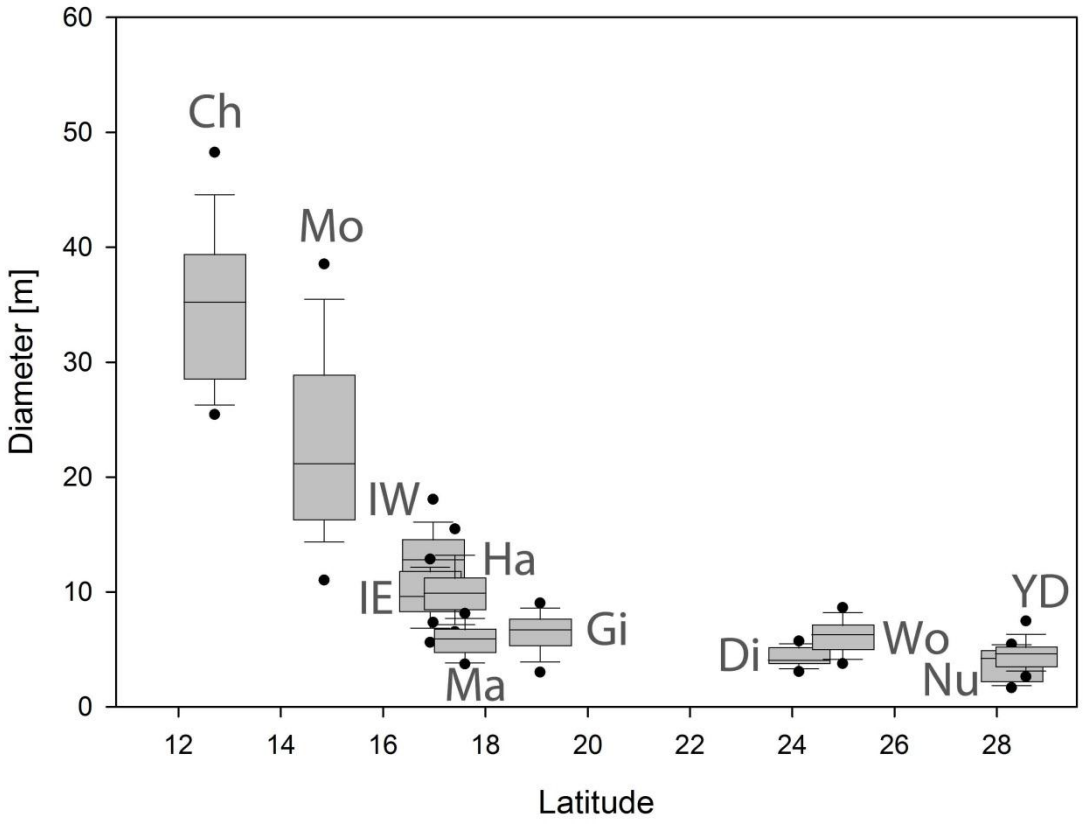

Fig. S3: Diameters of FCs decrease with southern latitude (n = 50 FCs/hotspot, Nu & YD = 25). Ch = Chamune/Chimalavera, Mo = Moscas, IW = Iona West, IE = Iona East, Ha = Hartmann, Ma = Marienfluss, Gi = Giribes, Di = Dieprivier, Wo = Wolwedans, Nu = Numees, YD = Yellow Dune.

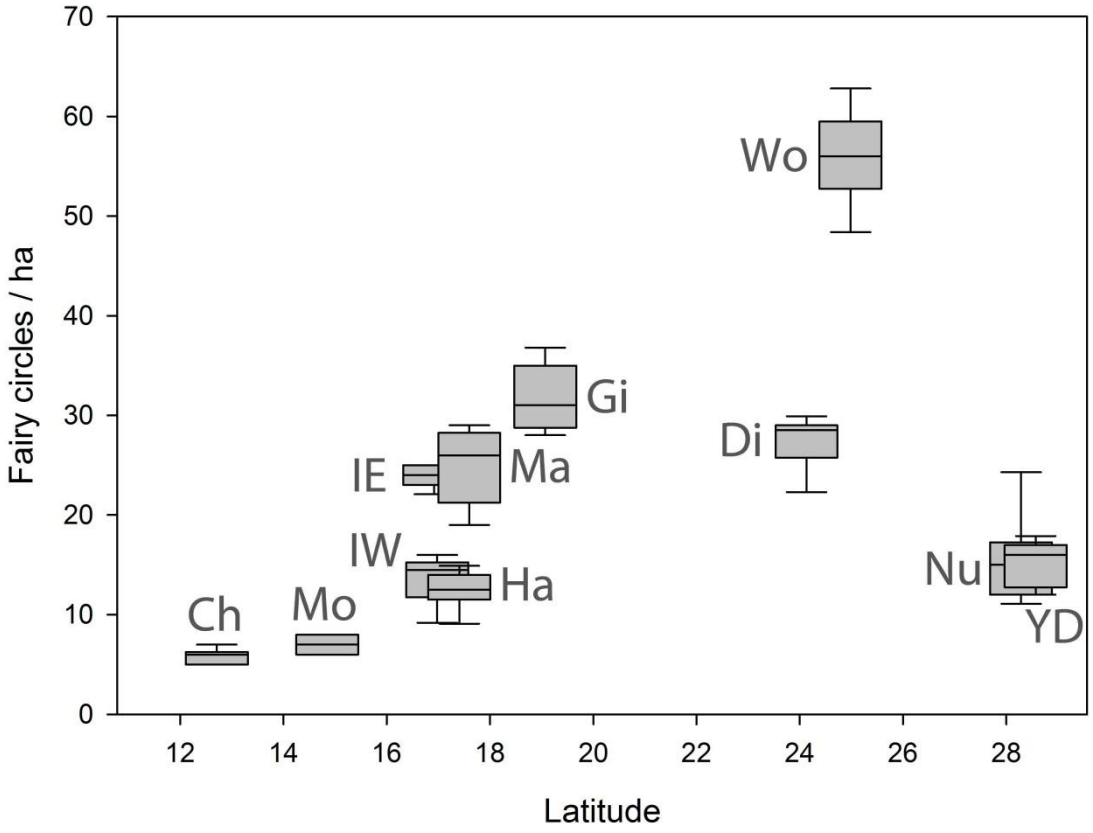

Fig. S4: Increase in FC density from North to South (n = 10 measured test areas/hotspot).

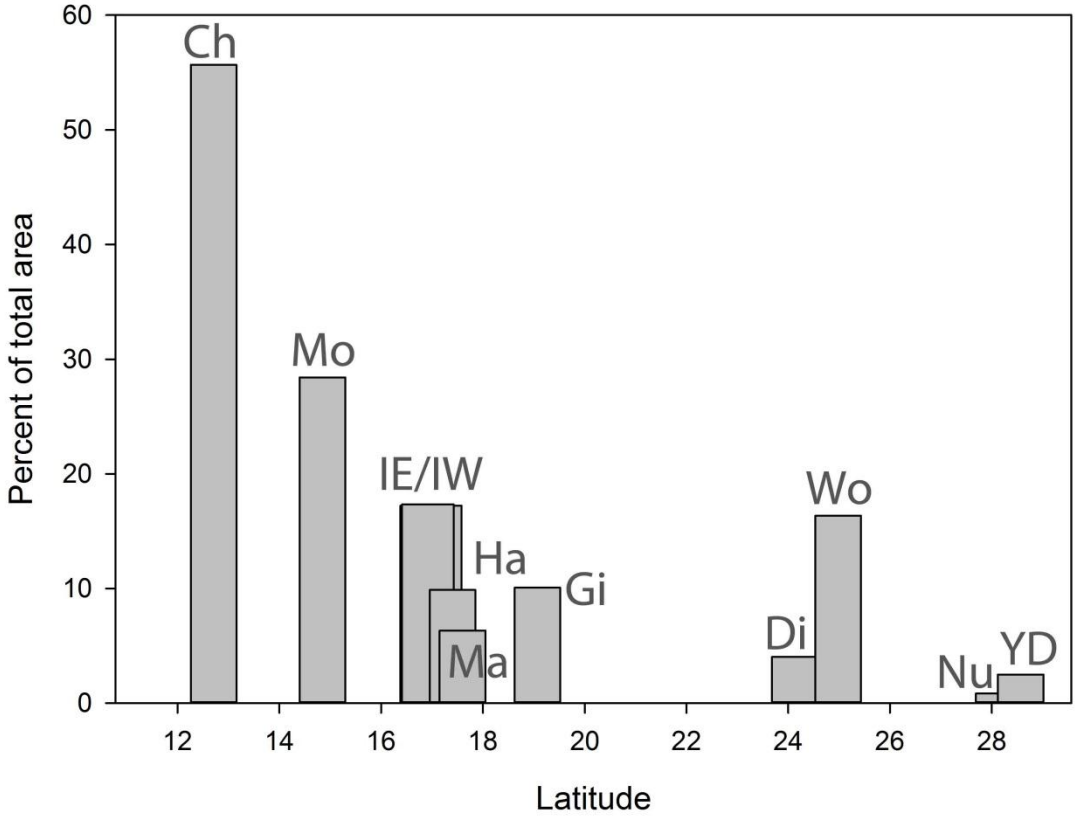

Fig. S5: Area proportion (cumulative surface of bare patches of FCs expressed as percentage of the total surface area of the landscape) from North to South (n = 10 measured test areas/hotspot).

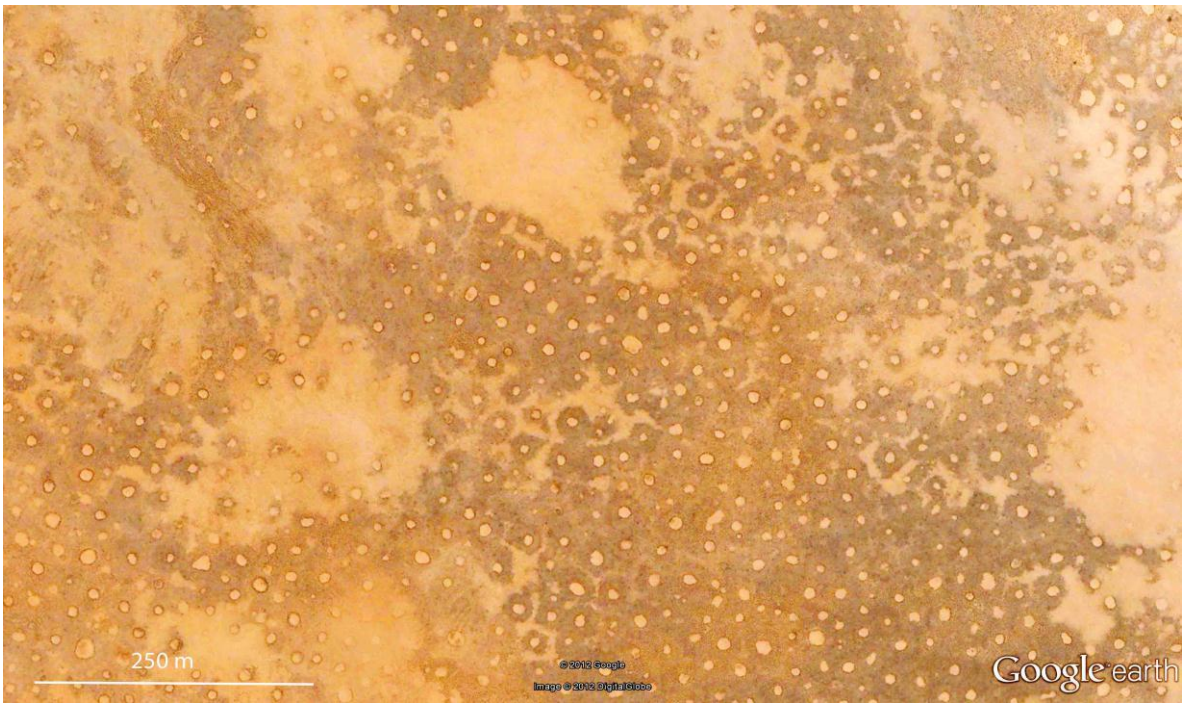

Fig. S6: Overlap of halos partly resulting in continuous grassland in the Hartmann Valley (NW Kaokoveld, Namibia).

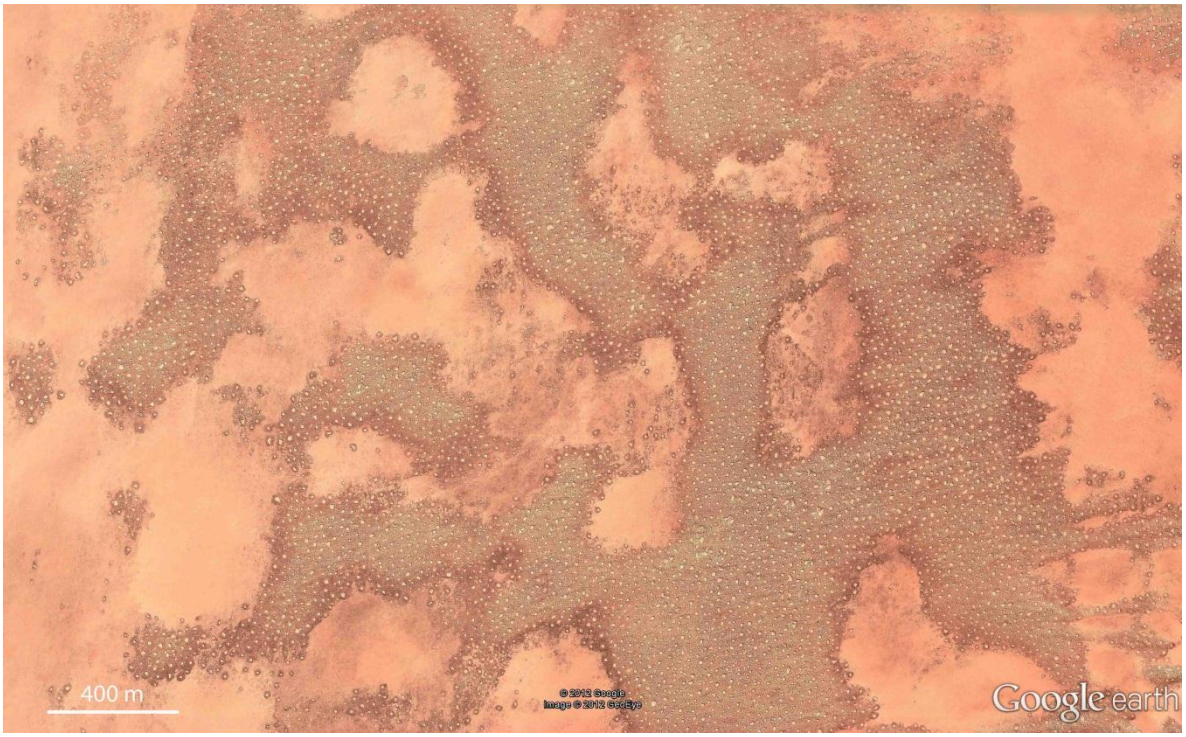

Fig. S7: Landscape of fused halos forming a perennial grassland with intermittent desert areas (Iona National Park, Angola). Boundaries are controlled by wind erosion and by sedimentation of airborn sand within FC halos and perennial belts.

Dynamics and life history

The observation of the formation or the disappearance of single new FCs led to first estimates with regard to the life history (*7*). In order to obtain robust evidence for changes over a longer period of time, we overlaid old aerial photographs (homogeneous FC landscape north of Featherlion Hill in Marienfluss Valley) dated 1956 with a modern Ikonos satellite image recorded in December 2006, i.e. half a century later. An area of 600 m × 400 m (24 ha) was overlaid using ArcGIS, partly shown in Fig. S8. The comparison shows that 97% of the 1956 FCs survived until 2006, while only 3% disappeared and an additional 30% (compared to the stock of 1956) were newly formed between 1956 and 2006. If we assume no additional interim dynamics during the 50 years, the present figures tell us that on average 9 new FCs have been created per km² and year, while 0.8 disappeared. Similar turnover rates have been observed in the course of our annual monitoring at Marienfluss, Giribesvlakte and Dieprivier. Clearly, FCs are perennial structures, which can reach a very advanced age, in the range of hundreds of years.

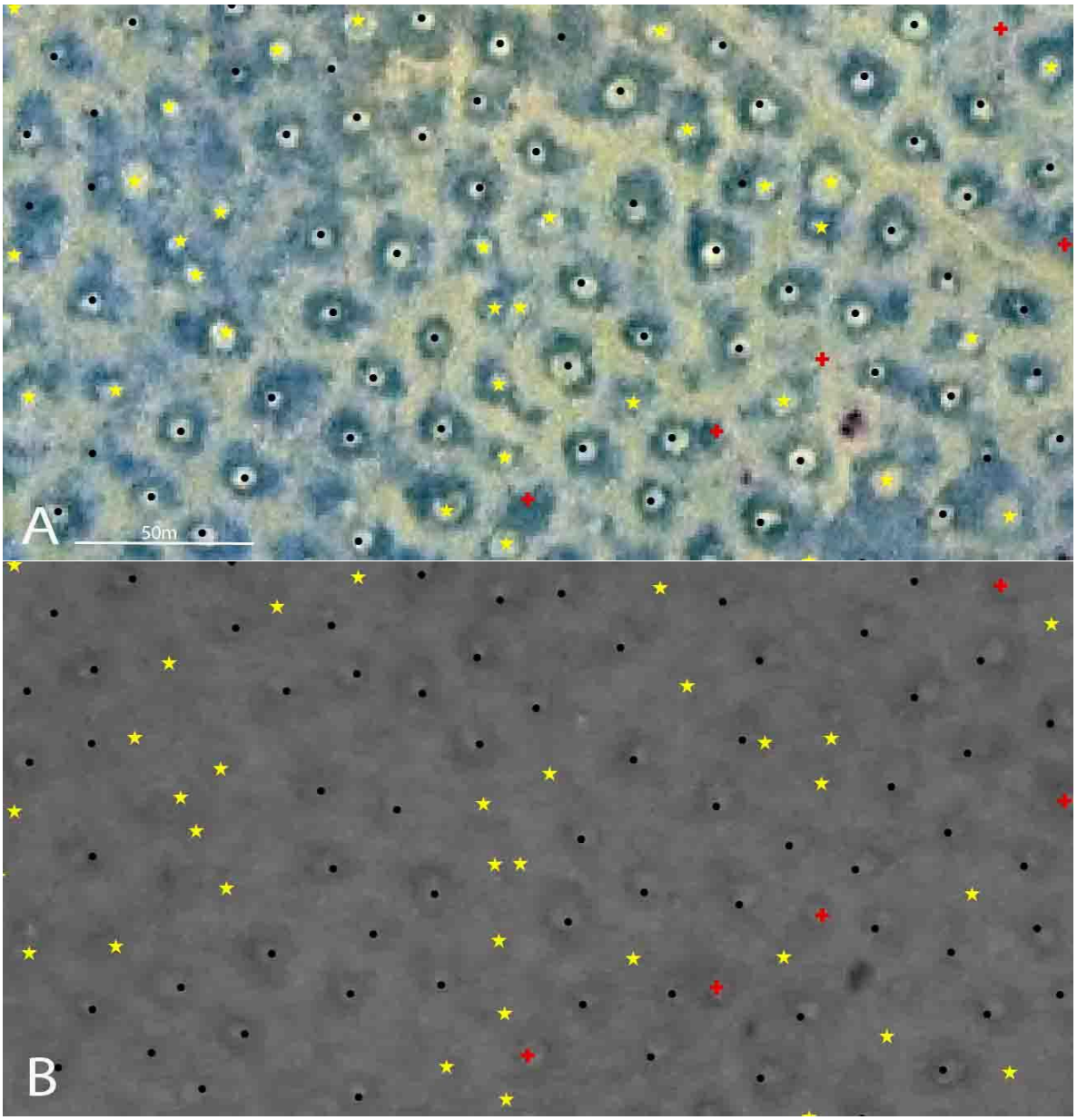

Fig. S8. Changes in a FC stock during half a century: S8A: 2006 Ikonos satellite image compared to S8B, a 1956 aerial photograph taken 3 km north of Featherlion Hill in Marienflussvalley, NW-Namibia. Yellow stars: newly formed FCs; red crosses: FCs that disappeared between 1956 and 2006; black dots: FCs present both in 1956 and 2006.

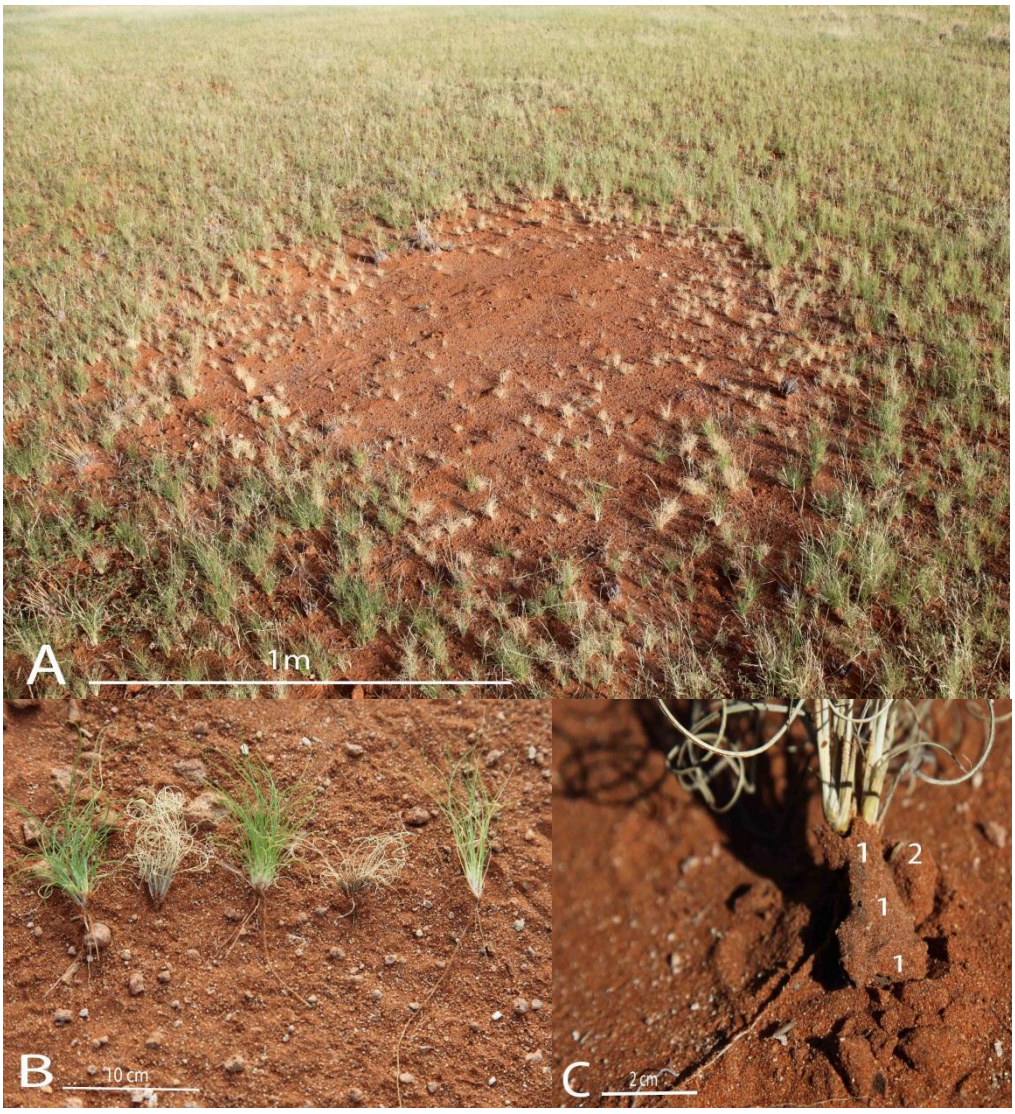

Fig. S9A: Young FC of probably 2 or 3 years of age. This estimation is based on comments by local managers and on comparisons with photos taken in the years before). S9B: Various states of root damage of young grass plants. S9C: Typical *Psammotermes* burrows with partly visible black tapetum (1) and termite worker (2) near the damaged roots of a young grass plant.

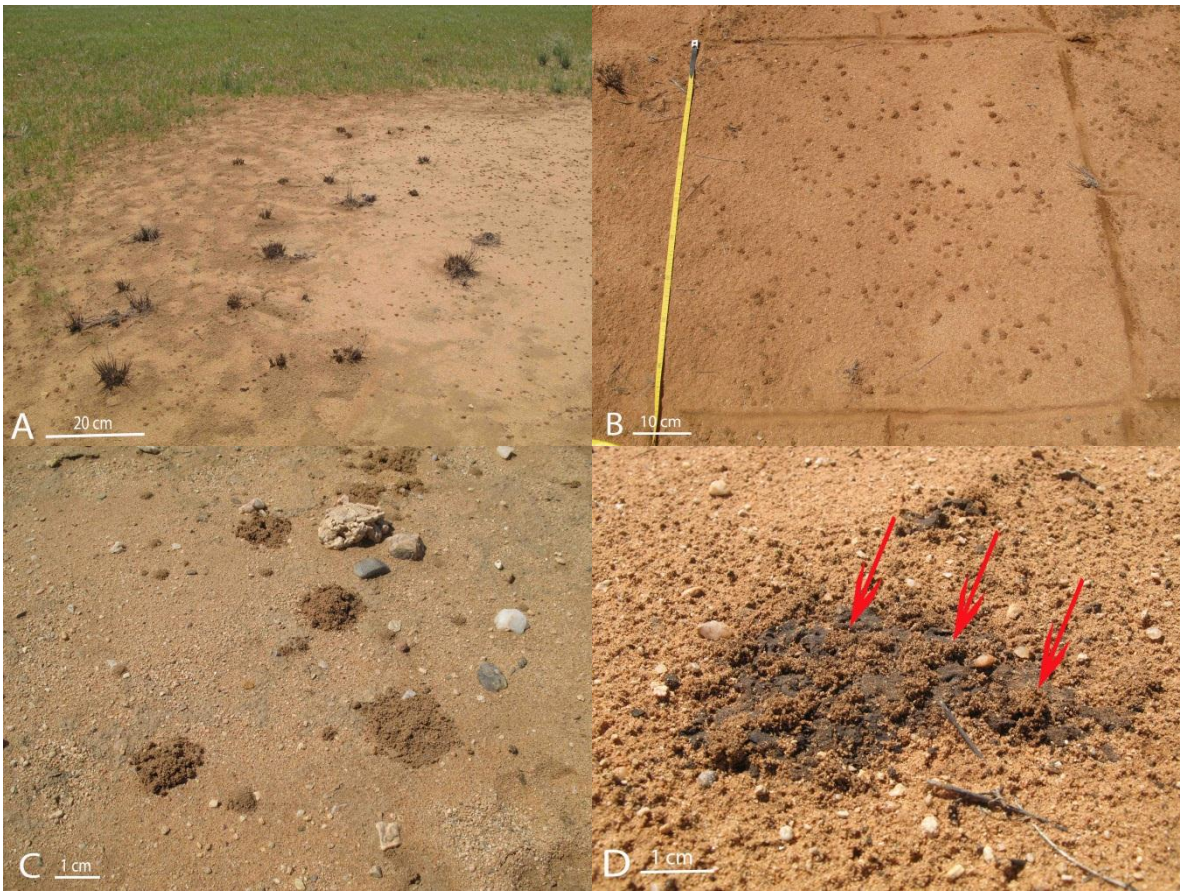

Fig. S10A: Pattern of soil dumps of *Psammotermes allocerus* within a FC at Giribesvlakte, Namibia. S10B: Number of soil dumps per square meter. S10C: Close up of freshly formed soil dumps in the morning. S10D: Accumulation of soil dumps (arrows) above belowground nest structure.

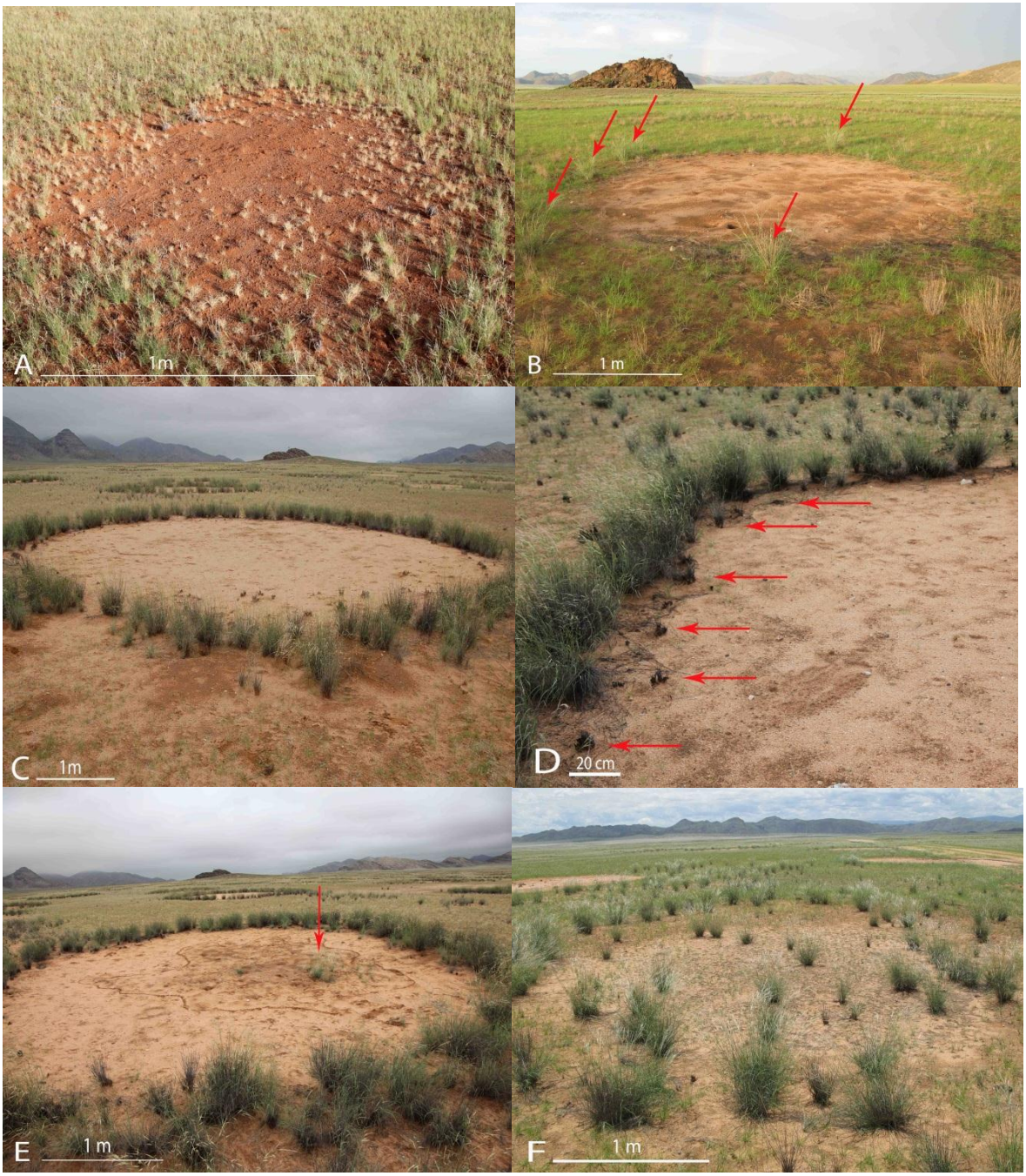

Fig. S11: Important states within the life history of FCs. S11A: First visible damage of the annual grass layer. S11B: Early state of the development of the perennial belt (PB) composed of single perennial grass tussocks (arrows). S11C: Growth phase of PB, indicated by stumps of dead grass tussocks at the inner margin of the PB. S11D: Detail of the before mentioned, dead grass tussocks marked with arrows. S11E: Invasion of *Messor* ants is excluding *Psammotermes* from the marked area around the arrow, allowing new growth of grasses. S11F: Dead FC, fully invaded by grasses.

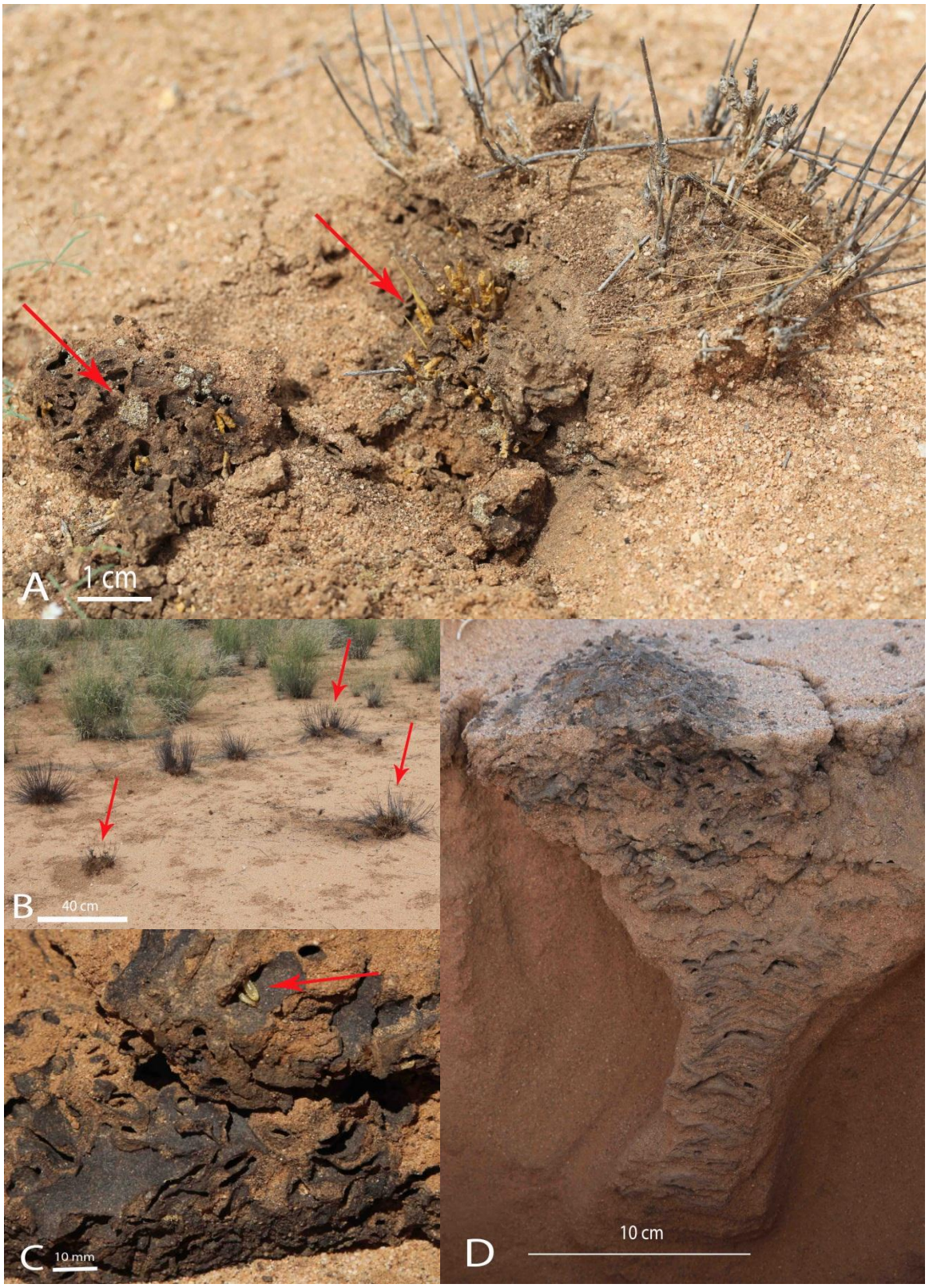
A
1 cm
B
40 cm
C
10 mm
D
10 cm

Fig S12: Nest forms: S12A: Foraging nest within a former grass tussock, partly opened on the left, showing the characteristic yellow colour of remaining grass shoots and greyish stored plant material (arrows). S12B: Group of foraging nests, located at foraged perennial grass tussocks (arrows). S12C and S12D: Permanent surface nests. S12C: Opened burrows with black tapetum and two termites (arrows). S12D: Fully excavated permanent surface nest from the centre of a FC. S12E: Opened burrows showing the characteristic black tapetum and greyish food stores marked by arrows.

Spatial and temporal patterns of distribution of water within FCs

October 2006, 8 month after last rain

Depth[cm]\Position	Matrix	Per. Belt	Half radius	Center	Half radius	Per. Belt	Matrix
10 cm	2.4	2.3	2.7	3.1			
20 cm	2.5	2.6	4.0	4.5			
30 cm	3.0	3.2	4.8	6.0			
40 cm	3.2	4.3	6.0	6.0			
50 cm	3.9	4.6	6.0	6.0			
60 cm	4.4	6.0	6.0	6.5			
70 cm	4.7	6.5	6.5	6.5			
80 cm	5.2	6.5	6.5	6.5			
90 cm	6.0	6.5	6.5	7.0			
100 cm	6.0	6.5	7.0	7.0			
$\sum H_2O$[mm] in 0-100cm:	**39.05**	**46.60**	**53.25**	**56.35**			

January 2007, 11 month after last rain

Depth[cm]\Position	Matrix	Per. Belt	Half radius	Center	Half radius	Per. Belt	Matrix
10 cm	4.6	1.7	3.7	4.6			
20 cm	3.9	2.7	4.7	5			
30 cm	3.6	3.4	6.2	6.7			
40 cm	5.4	4.3	5.9	6.4			
50 cm	4.3	3.9	6.4	6.2			
60 cm	3.7	3	6.8	7.6			
70 cm	5.1	3.6	5.6	9.1			
80 cm	3.8	4.7	6.7	6.7			
90 cm	4.9	5	5	7.0			
100 cm	4.7	5.2	5.9	6.8			
$\sum H_2O$[mm] in 0-100cm:	**43.95**	**37.75**	**55.80**	**65.00**			

March 2007, after 28 mm of rain Jan to Mar 2007

Depth[cm]\Position	Matrix	Per. Belt	Half radius	Center	Half radius	Per. Belt	Matrix
10 cm	4.9	4.6	5.3	4.4			
20 cm	5.9	5.4	7.2	8.9			
30 cm	6.0	5.6	9.3	9.1			
40 cm	5.3	5.5	8.6	9			
50 cm	5.2	5.6	8.2	9.2			
60 cm	4.1	5.5	8.5	8.8			
70 cm	5.2	5.4	9.1	9.4			
80 cm	4.9	5.2	9	9.5			
90 cm	4.9	5.4	9.2	10.1			
100 cm	4.6	5.3	8.2	9.9			
$\sum H_2O$[mm] in 0-100cm:	**51.15**	**53.15**	**81.15**	**85.55**			

December 2007, 8 months after last rain

Depth[cm]\Position	Matrix	Per. Belt	Half radius	Center	Half radius	Per. Belt	Matrix
10 cm		2.7		3.2			
20 cm		3.4		4.9			
30 cm		2		3.9			
40 cm		3.9		5			
50 cm		4.5		5.9			
60 cm		3.6		6.4			
70 cm		4.2		6.1			
80 cm		4.2		6.4			
90 cm		4.2		6.4			
100 cm		5.1		6.4			
$\sum H_2O$[mm] in 0-100cm:		**36.60**	-	**53.00**			

10 Feb 2008 (5 days after first good rains of the season (ca. 25mm)

Depth[cm]\Position	Matrix	Per. Belt	Half radius	Center	Half radius	Per. Belt	Matrix
10 cm	8.9	8.5	5.2	7.7			
20 cm	5.2	5.9	5.9	6.2			
30 cm	3.4	4.9	5.5	6.8			
40 cm	3.4	3.6	5.3	5.1			
50 cm	4	4	5	6.8			
60 cm	4.2	4.3	6.3	7.3			
70 cm	4	4.1	6.2	7.6			
80 cm	4.1	3.9	7.0	6.5			
90 cm	4.5	4.3	7.1	7.4			
100 cm	4.5	4.3	7.1	7.4			
$\sum H_2O$[mm] in 0-100cm:	**48.4**	**49.9**	**59.65**	**68.95**			

Tab. S1: Snapshots of spatial patterns of humidity within FCs 2006–2008.

A number of structurally identical, fully developed and undisturbed FCs of the 3 m size class in the south-eastern part of the central Namib Desert have been analyzed since October 2006. Trenches of 1 m depth were dug from the center of a FC through all the belts into the matrix grassland. Volumetric soil water content [Vol.-%] was measured using time domain reflectometry (TDR, Trime FM2 with P2G probe). The results are presented in Tab. S1. Measurements were taken at 10 cm intervals at four different positions (1 = Center of the FC ("Center"), 2 = halfway between center and margin ("Half radius"), 3 = perennial belt ("PB"), 4 = matrix grassland ("Matrix")). The data were classified into 8 color-coded categories and are presented in a form simulating a complete FC for better visual perception. Measurements have been taken and are shown on the left side only.

Color code:

< 2.9 Vol-%
3.0 – 3.9 Vol-%
4.0 – 4.9 Vol-%
5.0 – 5.9 Vol-%
6.0 – 6.9 Vol-%
7.0 – 7.9 Vol-%
8.0 – 8.9 Vol-%
> 9.0 Vol-%

Country	FC Hotspot	Bauc	Micro	Hodo	Psamm	Anoplo	Tetra	*Messor*
ANG	Chamune			+	+++		+	+
ANG	Moscas			+	+++		+	+
ANG	Iona			+	+++		+	++
NAM	Marienfluss			++	+++		++	++
NAM	Hartmann			++	+++	+	++	++
NAM	Giribes			+	+++		++	++
NAM	Brandberg			+	+++		+	+
NAM	Valencia			+	+++		+	+
NAM	Dieprivier			+	+++		++	
NAM	Wolwedans	+		+	++	+	+	
NAM	Namtib	+		++	+++	+	+	
NAM	Canyon	+			++		+	
SA	Numees		+		++			
SA	Yellow Dune		+		+++			

Tab. S2: Presence/absence and abundance of various termites and ants found in or directly adjacent to FCs along the FC distribution area. Bauc = *Baucaliotermes*, Micro = *Microhodotermes*, Hodo = *Hodotermes*, Psamm = *Psammotermes*, Anoplo = *Anoplolepis*, Mono/Tetra = *Tetramorium*. Abundance: +++ = observed at or next to almost all (80–100%) of the inspected FCs, ++ = observed at many (ca. 30%–80%) of the FCs, + = observed at some to many (5–30%) of the FCs.

Vernacular name	Taxon	Notes
Microorganisms		
Unidentified anaerobic bacteria in bare patch soil		CO production measured in termite nests of FCs at YD, Wolwedans, Giribes, Marienfluss, Dieprivier
Plants		
Giess bushman-grass	*Stipagrostis giessii*	Angola to Brandberg
Blue bushman-grass	*Stipagrostis hirtigluma ssp. hirt.*	Angola to Kaokoveld
Gemsbok tail grass	*Stipagrostis hochstetteriana*	Brandberg
Tall bushman-grass	*Stipagrostis ciliate var. cap.*	Brandberg to Sperrgebiet
Small bushman-grass	*Stipagrostis obtusa*	Dieprivier to Numees
Short-leaved bushman-grass	*Stipagrostis brevifolia*	Canyon
Single-awned bushman-grass	*Stipagrostis anomala*	Numees
Double-leaved bushman-grass	*Stipagrostis geminifolia*	Yellow dune
Watermelon	*Citrullus lanatus*	Dieprivier, Wolwedans
Camel thorn	*Acacia erioloba*	Dieprivier, Wolwedans
Winged Geigeria	*Geigeria alata*	Brandberg LB
Rattlepod	*Crotalaria sp.*	Hartmann
Lotononis	*Lotononis sp. HBG 140315*	Giribes
Tephrosia	*Tephrosia dregeana*	Dieprivier
	Gen. sp. Fabaceae HBG140.313	Hartmann
	Trianthema triquetra	Hartmann
	Pharnaceum sp.	Giribes
Simple Zygophyllum	*Zygophyllum simplex*	Brandberg
Shrubby spiderplant	*Cleome suffruticosa*	Iona, Marienfluss, Giribes
Kalahari Sourgrass	*Schmidtia kalahariensis*	Occasionally: Hartmann, Namtib
Arachnida: Scorpions and Spiders		
Scorpiones: Namib Sand Scorpion	*Parabuthus stridulus*	Dieprivier
Solifugae: Hexisopodidae	*Gen.sp.*	Probably foraging for termites
Araneae: Buck spoor spider	*Seothyra henscheli*	From Iona to Yellow dune, foraging for termites and ants
Araneae, Eresidea: Velvet spider	*cf. Gandanameno echinatus*	Potentially foraging for termites
Araneae: Zodariidae	*Psammorygma caligata*	Dieprivier
Araneae: Araneidae	*Argiope nigrovittata*	Dieprivier
Acari, Trombidiidae: Giant velvet mite,	*Gen. sp.*	Dieprivier, Giribes, Nymphes are foraging for

		termites
Insects		
Hemiptera: Unidentified aphids on grass in perennial belt		Marienfluss, Namtib, Giribes, Dieprivier
Sand termite	*Psammotermes allocerus*	All FC hotspots
Coleoptera: Tenebrionidae	*Somaticus sp.*	Observed at Dieprivier as foraging for Psammo-termes & Hodotermes
Coleoptera: Tenebrionidae	*Eurychora sp.*	Dieprivier
Coleoptera: Tenebrionidae	*Gonopus tibialis or G. pliciventris*	Dieprivier
Coleoptera: Scarabaeidae	*Scarabaeus denticollis*	Dieprivier
Coleoptera: Scarabaeidae	*Scarabaeus roderigesii*	Dieprivier
Coleoptera: Scarabaeidae	*Zophosis sp.*	Namtib
Coleoptera: Scarabaeidae	*cf. Temnorrhynchus sp.*	Dieprivier
Numerous (!) unidentified sand digging solitary bees and wasps		All FC hotspots
Harvester ant	*Messor denticornis*	Iona to Valencia
Pugnacious ant	*Anoplolepis steingroeveri (6)*	Hartmann to Namtib, observed as foraging for termites
Tetramorium ant	*Tetramorium sp.*	All FC hotspots except Succulent Karoo, observed as foraging for termites
Reptiles		
Web-footed gecko	*Palmatogecko rangei*	Dieprivier
Birds		
Chanting goshhawk	*Melierax canorus*	Kaokoveld to Wolwedans
Mammals		
Bat-eared fox	*Otocyon megalotis*	Dieprivier, Wolwedans
Black-backed jackal	*Canis mesomelas*	Dieprivier, Wolwedans
Golden mole	*Eremitalpa granti*	Dieprivier, Wolwedans, foraging along the PB on *Psammotermes*
Aardvark	*Orycteropus afer*	All FC hotspots, foraging on termites
Bushveld gerbil	*Gerbilliscus leucogaster*	Iona to Brandberg, foraging on Messor
Springbok	*Antidorcas marsupialis*	FCs used as mating site in Giribesvlakte

Tab. S3: List of organisms which make use of the FC environment (examples, not comprehensive).

FC Site/hotspot	Chamune	Moscas Bay	Iona West	Iona East	Hartmann	Marienfluss	Giribes	Dieprivier	Wolwedans	Numees	Yellow Dune
Latitude	-12.70825	-14.84730	-16.97776	-16.91779	-17.40161	-17.59900	-19.06857	-24.13111	-24.98327	-28.28608	-28.56762
Longitude	13.15145	12.22660	12.18977	12.32696	12.28093	12.59500	13.34081	15.89640	15.94314	16.94687	16.66956
Sample/Number of FC per ha											
01	5	8	15	24	14	19	28	28	57	25	16
02	6	8	15	24	14	28	37	29	63	17	17
03	7	6	12	25	12	26	35	25	59	18	15
04	6	6	13	23	15	29	34	29	58	15	18
05	6	7	15	24	14	27	28	22	61	12	16
06	5	7	16	25	13	29	30	29	52	13	13
07	6	7	11	22	10	22	35	30	54	15	16
08	6	6	9	24	9	26	32	27	48	17	12
09	5	8	14	25	12	22	29	29	53	12	17
10	7	7	16	23	12	19	30	26	55	11	12
Mean FC per ha	5.9	6.825	13.6	23.9	12.5	24.638	31.8	27.4	56	15.5	15.2
Standard error	0.2333	0.2388	0.7333	0.3145	0.6357	1.2527	1.0306	0.7775	1.4220	1.3017	0.6799
Median	6	6.75	14.5	24	12.625	26	31	28.5	56	15	16
SD	0.7379	0.7551	2.3190	0.9944	2.0104	3.9614	3.2592	2.4585	4.4969	4.1164	2.1499
Sample/Diameter [cm]											
	Chamune	Moscas Bay	Iona West	Iona East	Hartmann	Marienfluss	Giribes	Dieprivier	Wolwedans	Numees	Yellow Dune
01	3803	2898	1400	719	1346	500	740	370	650	208	455
02	2508	2003	1628	730	1095	770	880	405	612	546	340
03	4033	2693	1214	1182	980	750	760	550	564	190	345
04	2801	1598	1594	817	672	700	490	342	442	210	630
05	2697	1430	1609	840	670	380	750	405	461	160	360
06	2570	1498	2335	550	807	780	540	424	854	431	395
07	2667	1148	1419	857	1094	690	740	510	697	458	450
08	2644	3699	1309	953	929	640	620	275	622	360	550
09	4269	1598	1561	993	974	460	390	560	491	215	310
10	3016	1632	1942	692	633	490	860	390	502	178	630
11	3927	1046	1063	881	1775	450	820	350	701	523	590
12	3265	2355	1289	1199	877	640	670	488	637	539	400
13	2445	3983	1296	731	777	590	930	450	503	431	795
14	3776	2737	1425	994	996	470	970	550	848	458	490
15	4145	1528	1451	1337	1083	360	590	585	403	360	460
16	3301	1884	1135	1120	876	590	540	380	825	215	500
17	4630	2029	1290	1241	1108	380	550	400	891	378	340
18	4219	3483	1346	1174	1113	480	450	350	613	523	490
19	2866	1031	1566	830	1056	850	440	380	647	539	470
20	3626	3314	1207	821	1175	590	860	390	619	510	500
21	2623	1859	1130	413	1063	470	540	505	681	423	530
22	2963	1490	1326	907	942	430	530	520	479	214	470
23	3401	2416	1025	868	838	610	430	330	633	447	240
24	3606	2647	1244	685	857	510	630	480	549	324	310
25	2692	2974	1181	963	909	500	760	480	743	433	335
26	3031	1501	775	849	741	850	530	530	335		

27	4252	1712	716	1017	923	650	260	330	463		
28	3537	2774	935	1102	742	740	350	370	782		
29	3391	1322	734	1103	1208	680	510	405	785		
30	3534	1922	1124	823	1168	670	820	550	762		
31	4479	2788	1388	1224	1229	520	390	342	664		
32	2583	2841	1451	1424	747	440	670	405	553		
33	3961	1915	1314	1173	947	630	590	424	728		
34	2916	2259	1060	1214	1042	400	830	510	356		
35	2744	1528	1265	839	932	550	710	275	874		
36	4543	3748	1270	870	997	580	670	560	638		
37	3634	2955	972	1199	841	670	720	390	558		
38	3511	1874	1515	1103	581	640	690	350	462		
39	3545	2021	1255	1055	873	380	750	488	504		
40	3248	4104	1585	1210	1139	460	670	450	648		
41	2755	2113	840	1188	710	590	480	550	705		
42	3701	2979	1566	1181	825	780	600	585	549		
43	3791	2192	1156	568	1330	480	310	380	411		
44	3703	2880	859	684	1128	670	760	400	637		
45	5063	3555	968	687	1227	450	680	350	686		
46	4131	2237	995	1061	1613	360	700	380	711		
47	5096	2114	1033	908	1494	650	880	390	710		
48	2909	1798	733	956	1063	610	290	505	426		
49	3044	1979	1299	1101	1030	470	810	520	392		
50	3766	3052	1693	1000	1016	610	590	330	494		
Mean Diameter	3467.22	2302.72	1269.72	960.72	1003.82	572.2	634.8	432.76	610	262.8	455.4
Standard error	96.9234	111.8252	44.3994	31.0352	33.9816	18.5259	24.6233	11.9345	20.0486	71.3655	24.9532
Median	3522.5	2113.5	1279.5	959.5	988	590	670	405	627.5	208	460
SD	685.3521	790.7238	313.9509	219.4521	240.2859	130.9976	174.1128	84.3894	141.7648	159.5782	124.7658
Surface area FC	5567.8108	2840.8910	1721.1728	1731.6544	988.7611	633.2436	1005.9366	402.8232	1635.7516	84.0334	247.4567
Proportion FC area/ha	55.68%	28.41%	17.21%	17.32%	9.89%	6.33%	10.06%	4.03%	16.36%	0.84%	2.47%

Tab. S4: Raw data for Fig. S3, S4 and S5

FC number	Termite activity	Grass individuals
1	0	700
2	0	400
3	0	50
4	5	300
5	20	8
6	20	1
7	25	1
8	30	50
9	30	1
10	30	200
11	30	200
12	40	1
13	40	1
14	40	1
15	40	10
16	45	1
17	45	2
18	45	8
19	50	1
20	50	1
21	50	1
22	50	1
23	50	1
24	50	1
25	50	20
26	50	1
27	50	1
28	50	20
29	50	1
30	55	1
31	60	1
32	60	1
33	60	1
34	60	1
35	60	20
36	70	20
37	70	1
38	70	1
39	70	1

40	80	1
41	80	1
42	80	1
43	80	1
44	80	10
45	90	1
46	100	1
47	100	1
48	20	31
49	50	30
50	10	52
51	8	57
52	12	640
53	3	1000
54	5	180
55	50	33
56	50	30
57	20	31
58	30	181
59	10	63
60	5	20
61	20	81
62	15	110
63	4	8
64	60	23
65	20	34
66	7	145
67	0	16
68	12	120
69	20	120
70	10	200
71	10	53
72	3	15
73	10	141
74	40	71
75	60	104
76	30	70
77	30	15
78	10	90
79	20	130

80	0	915
81	0	202
82	80	40
83	80	7

Tab. S5: Raw data for Fig. 3C. Measurements taken at Giribesvlakte, Namibia 10. March 2008. Compare also Fig. S10.

References and Notes

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