**Supplementary Information**

# Testing for consistency in the impacts of a burrowing ecosystem engineer on soil and vegetation characteristics across biomes

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Fig. S.1: An example of different burrow age classes at the semi-arid savannah (Khamab Kalahari Reserve): a) a fresh burrow, b) an abandoned burrow, and c) a collapsed burrow.

Table S.1: The effects of burrowing mammals on vegetation cover and species richness at different study sites (see Fig. 2-4). Models also included burrows and associated microsites' locations as a random effect to account for the spatial clustering of sets of microsites. Detailed results are presented in Table S.2 – S.3.

| Response variable | Study site | Fixed effects | Ranking of factor levels | $Chi^2$ | df | p |
|---|---|---|---|---|---|---|
| Cover | Mesic grassland | Microsite | C > IA > BE | 17.01 | 2 | *** |
| | | Age | COL > AB > FR | 5.62 | 2 | p = 0.06 |
| | Semi-arid savannah | Microsite | C > IA > BE | 0.99 | 2 | |
| | | Age | COL > AB > FR | 7.71 | 2 | * |
| | Arid scrubland | Microsite | C > IA > BE | 56.20 | 2 | *** |
| | | Age | FR > AB | 0.54 | 1 | |
| Richness | Mesic grassland | Microsite | BE > C > IA | 12.79 | 2 | ** |
| | | Age | COL > AB > FR | 6.02 | 2 | * |
| | | Microsite:Age | | 15.01 | 4 | ** |
| | Semi-arid savannah | Microsite | C > IA > BE | 19.54 | 2 | *** |
| | | Age | COL > AB > FR | 18.87 | 2 | *** |
| | Arid scrubland | Microsite | C > IA > BE | 38.49 | 2 | *** |
| | | Age | AB > FR | 0.06 | 1 | |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S.2: Pairwise post-hoc analyses of vegetation cover and species richness (see Table S.1 and Fig. 2-4). Models also included burrow location as a random effect to account for the spatial clustering of sets of microsites at each burrow. BE = "Burrow entrance", IA = "Impacted Area", C = "Control". Microsite type and burrow age were considered simultaneously as fixed effects in analyses, but are reported here in two separate tables for clarity (also see Table S.3). Post-hoc results are only reported where at least one pair of factor levels differed significantly.

| Response variable | Study site | Microsites | Estimate | SE | z value | P |
|---|---|---|---|---|---|---|
| Vegetation cover | Mesic grassland | IA vs BE | 0.64 | 0.38 | 1.68 | |
| | | C vs BE | 1.95 | 0.47 | 4.12 | *** |
| | | IA vs C | -1.31 | 0.48 | -2.73 | * |
| | Arid scrubland | IA vs BE | 4.76 | 0.92 | 5.20 | *** |
| | | C vs BE | 6.29 | 0.93 | 6.74 | *** |
| | | IA vs C | -1.53 | 0.32 | -4.75 | *** |
| Species richness | Mesic grassland | IA vs BE | -0.36 | 0.11 | -3.42 | ** |
| | | C vs BE | -0.25 | 0.10 | -2.43 | * |
| | | IA vs C | -0.11 | 0.11 | -1.00 | |
| | Semi-arid savannah | IA vs BE | 0.04 | 0.20 | 0.20 | |
| | | C vs BE | 0.64 | 0.17 | 3.72 | *** |
| | | IA vs C | -0.60 | 0.17 | -3.54 | ** |
| | Arid scrubland | IA vs BE | 3.53 | 0.59 | 6.02 | *** |
| | | C vs BE | 3.63 | 0.59 | 6.20 | *** |
| | | IA vs C | -0.10 | 0.14 | -0.75 | |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S.3: Pairwise post-hoc analyses of vegetation cover and species richness (see Table S.1 and Fig. 2-4). Models also included burrow location as a random effect to account for the spatial clustering of sets of microsites at each burrow. FR = "Fresh", AB = "Abandoned", COL = "Collapsed". Microsite type and burrow age were considered simultaneously as fixed effects in analyses, but are reported here in two separate tables for clarity (also see Table S.2). Post-hoc results are only reported where at least one pair of factor levels differed significantly.

| Response variable | Study site | Age | Estimate | SE | z value | P |
|---|---|---|---|---|---|---|
| Vegetation cover | Mesic grassland | FR vs AB | -1.60 | 0.80 | -2.01 | |
| | | FR vs COL | -1.96 | 0.83 | -2.36 | * |
| | | COL vs AB | 0.35 | 0.37 | 0.95 | |
| | Semi-arid savannah | FR vs AB | -2.28 | 1.11 | -2.05 | |
| | | FR vs COL | -2.90 | 1.06 | -2.72 | * |
| | | COL vs AB | 0.62 | 0.58 | 1.06 | |
| Species richness | Mesic grassland | FR vs AB | -1.49 | 0.51 | -2.92 | ** |
| | | FR vs COL | -1.59 | 0.51 | -3.10 | ** |
| | | COL vs AB | 0.11 | 0.12 | 0.91 | |
| | Semi-arid savannah | FR vs AB | -0.79 | 0.21 | -3.71 | *** |
| | | FR vs COL | -0.79 | 0.20 | -3.87 | *** |
| | | COL vs AB | 0.002 | 0.20 | 0.01 | |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S.4: Average cover (%) of common plant species (i.e. >3 occurrences) occurring at the different microsites (with the total number of microsites containing each of the vascular plant species in brackets) at the semi-arid savannah site. n = 71 for each microsite. Significant p-values indicate species where a species' occurrence across microsites differed significantly from what would be expected by chance.

| Plant species | Burrow entrance | Impacted area | Control | p |
|---|---|---|---|---|
| *Acanthosicyos naudinianus* | 0.2 (4) | 0.3 (5) | 1.1 (12) | * |
| *Elephantorrhiza elephantina* | 0.0 (0) | 0.4 (3) | 0.3 (2) | |
| *Gisekia pharnaceoides* | 0.4 (4) | 0.0 (0) | 0.2 (4) | |
| *Ledebouria undulata* | 0.1 (1) | 0.01 (1) | 0.3 (5) | |
| *Mollugo cerviana* | 0.03 (2) | 0.03 (2) | 0.1 (1) | |
| *Ornithogalum seineri* | 0.0 (0) | 0.03 (2) | 0.1 (3) | |
| *Schmidtia pappophoroides* | 0.4 (6) | 0.6 (9) | 0.6 (21) | ** |
| *Stipagrostis uniplumis* | 2.5 (22) | 2.5 (19) | 4.8 (30) | |
| *Talinum crispatulum* | 0.01 (1) | 0.2 (2) | 0.1 (2) | |
| *Tribulus zeyheri* | 0.8 (5) | 0.5 (2) | 0.0 (0) | |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S.5: Average cover (%) of common plant species (i.e. >3 occurrences) occurring at the different microsites (with the total number of microsites containing each of the vascular plant species in brackets) at the mesic grassland site. Plant species shown in bold are unique to a specific microsite. n = 60 for each microsite. Significant p-values indicate species where a species' occurrence across microsites differed significantly from what would be expected by chance.

| Plant species | Burrow entrance | Impacted area | Control | p |
|---|---|---|---|---|
| *Acalypha angustata* | 1.3 (6) | 1.4 (8) | 1.0 (8) | |
| *Aristida congesta* | 0.1 (2) | 0.1 (1) | 0.2 (1) | |
| *Bidens bipinnata* | 0.4 (5) | 0.1 (4) | 0.1 (2) | |
| *Bidens pilosa* | 0.8 (5) | 0.5 (2) | 0.02 (1) | |
| *Campuloclinium macrocephalum* | 0.9 (12) | 0.4 (5) | 0.4 (5) | |
| ***Cheilanthes viridis*** | **6.4 (13)** | 0.0 (0) | 0.0 (0) | *** |
| *Commelina africana* | 0.3 (3) | 0.2 (3) | 0.2 (1) | |
| *Conyza bonariensis* | 1.3 (9) | 0.5 (5) | 0.2 (2) | |
| *Conyza podocephala* | 0.6 (6) | 0.5 (7) | 1.0 (7) | |
| *Conyza sp1* | 0.7 (6) | 0.1 (2) | 0.0 (0) | * |
| *Cymbopogon excavatus* | 0.4 (3) | 1.2 (3) | 3.1 (9) | |
| *Cynodon dactylon* | 8.1 (26) | 12.3 (27) | 5.3 (16) | |
| *Eragrostis chloromelas* | 2.4 (15) | 8.7 (25) | 17.8 (36) | ** |
| *Eragrostis curvula* | 0.2 (1) | 2.4 (5) | 1.4 (4) | |
| *Eragrostis lehmanniana* | 3.9 (17) | 11.5 (25) | 13.0 (21) | |
| *Eragrostis plana* | 0.1 (2) | 0.3 (1) | 0.1 (1) | |
| *Eragrostis tef* | 0.1 (1) | 0.4 (3) | 4.2 (7) | |
| *Helichrysum rugulosum* | 1.2 (6) | 2.3 (10) | 2.9 (12) | |
| *Hermannia depressa* | 0.02 (1) | 0.4 (2) | 0.1 (1) | |
| *Heteropogon contortus* | 0.3 (3) | 1.0 (1) | 1.8 (5) | |
| *Hilliardiella oligocephala* | 1.8 (11) | 1.0 (6) | 0.7 (8) | |
| *Hyparrhenia hirta* | 1.4 (6) | 0.8 (7) | 2.0 (6) | |
| *Hypoxis iridifolia* | 0.0 (0) | 0.3 (2) | 0.4 (3) | |
| *Hypoxis sp3* | 0.7 (3) | 0.4 (2) | 0.3 (3) | |
| Morpho *sp37* | 0.7 (4) | 0.3 (1) | 0.0 (0) | |
| Morpho *sp48* | 1.1 (4) | 1.4 (5) | 1.2 (4) | |
| *Grass sp1* | 1.1 (3) | 1.0 (1) | 4.7 (4) | |
| *Oenothera rosea* | 0.4 (4) | 0.1 (2) | 0.2 (5) | |
| *Oenothera sp* | 0.4 (4) | 0.1 (1) | 0.0 (0) | |
| *Oxalis corniculata* | 1.3 (23) | 0.3 (3) | 0.3 (6) | *** |
| *Panicum natalense* | 0.5 (3) | 1.4 (5) | 2.1 (4) | |
| *Pelargonium luridum* | 0.1 (2) | 0.02 (1) | 0.1 (1) | |
| ***Pellaea calomelanos*** | **0.4 (4)** | 0.0 (0) | 0.0 (0) | * |
| *Pollichia campestris* | 1.2 (6) | 0.0 (0) | 0.02 (1) | ** |
| *Schkuhria pinnata* | 0.4 (4) | 0.7 (4) | 0.3 (2) | |
| *Senecio inornatus* | 0.5 (7) | 0.7 (6) | 1.1 (12) | |
| *Senecio sp2* | 0.5 (9) | 0.02 (1) | 0.1 (2) | ** |
| *Setaria sphacelata1* | 0.02 (1) | 0.2 (3) | 0.1 (1) | |

| | | | | |
|---|---|---|---|---|
| *Solanum tomentosum* | 0.3 (5) | 0.2 (6) | 0.2 (5) | |
| *Tagetes minuta* | 1.1 (13) | 0.2 (4) | 0.03 (2) | ** |
| *Teucrium trifidum* | 0.3 (4) | 0.02 (1) | 0.0 (0) | |
| *Themeda triandra* | 0.3 (1) | 1.6 (4) | 0.7 (2) | |
| *Thesium utile* | 0.1 (2) | 0.3 (2) | 0.0 (0) | |
| *Urochloa panicoides* | 0.1 (2) | 0.3 (1) | 0.02 (1) | |
| *Verbena bonariensis* | 5.0 (15) | 1.0 (8) | 0.5 (3) | ** |
| *Verbena brasiliensis* | 0.6 (5) | 0.5 (3) | 0.5 (4) | |

* p < 0.05, ** p < 0.01, *** p < 0.001

Table S.6: Average cover (%) of common plant species (i.e. >3 occurrences) occurring at the impacted area and control microsites (with the total number of microsites containing each of the vascular plant species in brackets) at the arid scrubland site. n = 11 for each microsite. No species differed significantly in frequency of occurrence between the two microsites.

| Plant species | Impacted area | Control |
|---|---|---|
| *Atriplex lindleyi* ssp. *inflata* | 3.3 (4) | 1.4 (6) |
| *Augea capensis* | 2.2 (6) | 3.9 (9) |
| *Crassula subaphylla* | 0.5 (5) | 0.3 (2) |
| *Drosanthemum hispidum* | 0.9 (7) | 1.3 (6) |
| *Drosanthemum praecultum* | 1.0 (2) | 0.6 (6) |
| *Galenia fruticosa* | 0.7 (7) | 1.5 (9) |
| *Malephora lutea* | 15.6 (10) | 33.2 (11) |
| *Osteospermum sinuatum* | 0.6 (5) | 2.5 (9) |
| *Phyllobolus nitidus* | 0.6 (5) | 2.8 (8) |
| *Phyllobolus splendens* | 1.6 (7) | 1.8 (6) |
| *Psilocaulon junceum* | 17.6 (10) | 31.2 (11) |
| *Pteronia pallens* | 7.1 (11) | 7.5 (10) |
| *Ruschia spinosa* | 2.5 (9) | 3.0 (9) |

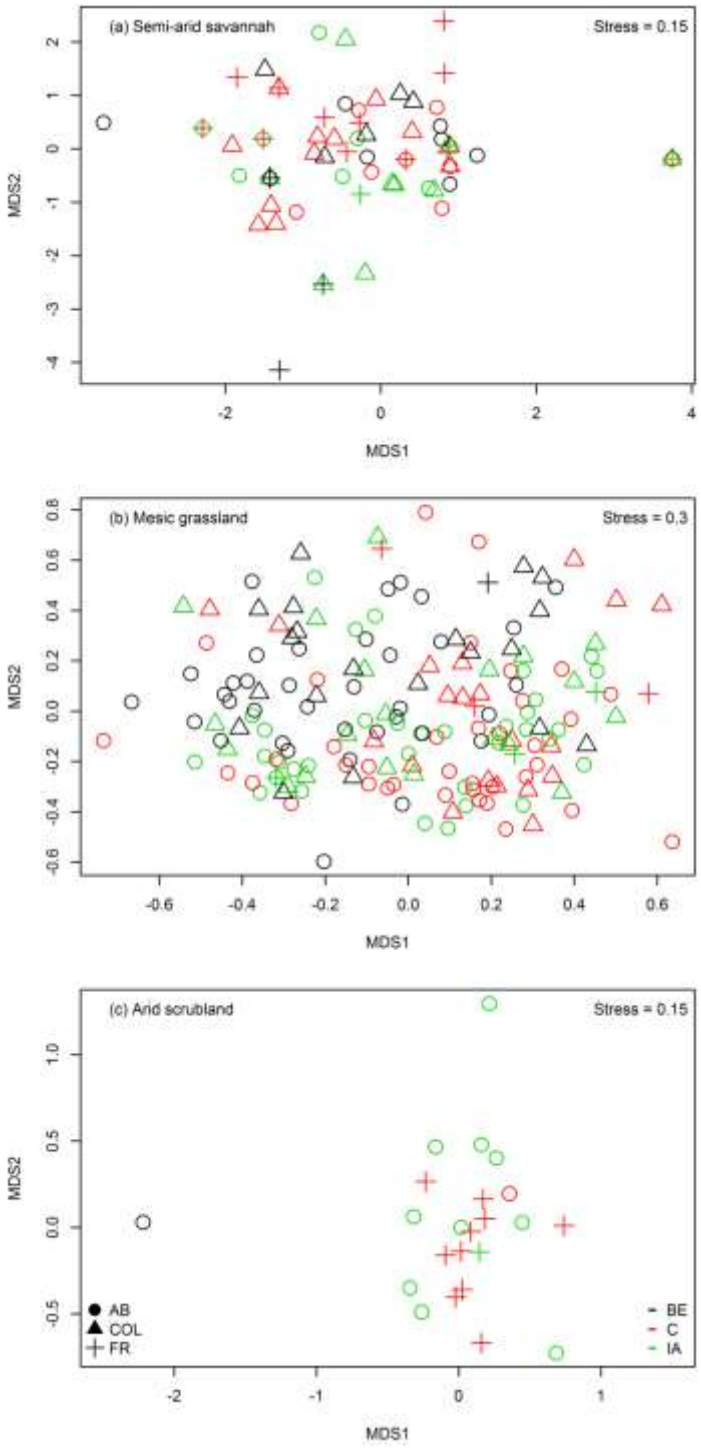


Fig. S.2: Vegetation composition at the different study sites. Colour indicates microsites (i.e. black = burrow entrance, red = control, green = impacted area) and symbols indicates burrow age (i.e. ○ = abandoned, △ = collapsed, + = fresh). BE = “Burrow entrance”, IA = “Impacted area”, C = “Control”. AB = “Abandoned”, COL = “Collapsed”, FR = “Fresh”

Table S.7: Overall model results of the effects of burrowing mammals on soil temperature, moisture and compaction at different study sites (see Fig. 5-7). Models also included burrow location as a random effect to account for the spatial clustering of sets of microsites at each burrow. Detailed results presented Table S.8 – S.9).

| Response variable | Study site | Fixed effects | $Chi^2$ | Df | p |
|---|---|---|---|---|---|
| Temperature | Mesic grassland | Microsite | 135.73 | 2 | *** |
| | | Time | 103.19 | 1 | *** |
| | | Age | 2.82 | 2 | |
| | | Microsite:Time | 23.80 | 2 | *** |
| | Semi-arid savannah | Microsite | 230.72 | 2 | *** |
| | | Time | 75.66 | 1 | *** |
| | | Age | 0.94 | 2 | |
| | | Microsite:Time | 21.57 | 2 | *** |
| | Arid scrubland | Microsite | 2.46 | 2 | |
| | | Time | 4.23 | 1 | * |
| | | Age | 0.04 | 1 | |
| | | Microsite:Time | 21.30 | 2 | *** |
| Moisture | Mesic grassland | Microsite | 51.31 | 2 | *** |
| | | Age | 2.84 | 2 | |
| | Semi-arid savannah | Microsite | 23.03 | 2 | *** |
| | | Age | 3.39 | 2 | |
| | Arid scrubland | Microsite | 4.34 | 2 | |
| | | Age | 2.82 | 1 | |
| Compaction | Mesic grassland | Microsite | 25.62 | 2 | *** |
| | | Age | 2.11 | 2 | |
| | Semi-arid savannah | Microsite | 64.85 | 2 | *** |
| | | Age | 2.97 | 2 | |
| | Arid scrubland | Microsite | 2.40 | 2 | |
| | | Age | 0.12 | 1 | |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S.8: Pairwise post-hoc analyses of soil temperature (see Table S.7 and Fig. 5). Models also included burrow location as a random effect to account for the spatial clustering of sets of microsites at each burrow. BE = "Burrow entrance", IA = "Impacted Area", C = "Control". Post-hoc results are only reported where at least one pair of factor levels differed significantly.

| Study site | Microsites | Fixed effects | $Chi^2$ | df | P |
|---|---|---|---|---|---|
| Mesic grassland | IA vs BE | Microsite | 113.96 | 1 | *** |
| | | Time | 83.42 | 1 | *** |
| | | Age | 1.48 | 2 | |
| | | Microsite:Time | 21.27 | 1 | *** |
| | C vs BE | Microsite | 155.66 | 1 | *** |
| | | Time | 60.38 | 1 | *** |
| | | Age | 2.93 | 2 | |
| | | Microsite:Time | 10.41 | 1 | ** |
| | IA vs C | Microsite | 6.39 | 1 | * |
| | | Time | 104.28 | 1 | *** |
| | | Age | 2.72 | 2 | |
| | | Microsite:Time | 5.17 | 1 | * |
| Semi-arid savannah | IA vs BE | Microsite | 140.29 | 1 | *** |
| | | Time | 61.26 | 1 | *** |
| | | Age | 1.35 | 2 | |
| | | Microsite:Time | 13.58 | 1 | *** |
| | C vs BE | Microsite | 163.02 | 1 | *** |
| | | Time | 77.89 | 1 | *** |
| | | Age | 1.51 | 2 | |
| | | Microsite:Time | 14.83 | 1 | *** |
| | IA vs C | Microsite | 1.50 | 1 | |
| | | Time | 72.06 | 1 | *** |
| | | Age | 0.26 | 2 | |
| | | Microsite:Time | 0.05 | 1 | |
| Arid scrubland | IA vs BE | Microsite | 0.72 | 1 | |
| | | Time | 3.98 | 1 | * |
| | | Age | 0.10 | 1 | |
| | | Microsite:Time | 19.14 | 1 | *** |
| | C vs BE | Microsite | 1.58 | 1 | |
| | | Time | 3.36 | 1 | |
| | | Age | 0.06 | 1 | |
| | | Microsite:Time | 7.1 | 1 | ** |
| | IA vs C | Microsite | 1.21 | 1 | |
| | | Time | 5.27 | 1 | * |
| | | Age | 0.002 | 1 | |
| | | Microsite:Time | 2.96 | 1 | |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table S.9: Pairwise post-hoc analyses of soil moisture and soil compaction (see Table S.7 and Figures 6-7). Models also included burrow location as a random effect to account for the spatial clustering of sets of microsites at each burrow. BE = "Burrow entrance", IA = "Impacted Area", C = "Control". Microsite type and burrow age were considered simultaneously as fixed effects in analyses but are reported here in two separate tables for clarity. Post-hoc results are only reported where at least one pair of factor levels differed significantly.

| Response variable | Study site | Microsites | Estimate | SE | z value | P |
|---|---|---|---|---|---|---|
| Moisture | Mesic grassland | IA vs BE | 2.17 | 0.62 | 3.51 | ** |
| | | C vs BE | 4.43 | 0.62 | 7.16 | *** |
| | | IA vs C | -2.26 | 0.62 | -3.65 | *** |
| | Semi-arid savannah | IA vs BE | -0.11 | 0.25 | -0.43 | |
| | | C vs BE | -1.08 | 0.25 | -4.36 | *** |
| | | IA vs C | 0.97 | 0.25 | 3.92 | *** |
| Compaction | Mesic grassland | IA vs BE | 3.63 | 1.04 | 3.47 | ** |
| | | C vs BE | 4.79 | 1.05 | 4.57 | *** |
| | | IA vs C | -1.17 | 0.39 | -3.02 | ** |
| | Semi-arid savannah | IA vs BE | 1.51 | 0.19 | 8.05 | *** |
| | | C vs BE | 1.15 | 0.19 | 5.91 | *** |
| | | IA vs C | 0.36 | 0.13 | 2.72 | * |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$