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Descriptions of movement and burrow morphology of a tropical millipede, *Spirostreptus heros* Porat, 1872 (Diplopoda: Spirostreptida: Spirostreptidae) in the Kalahari desert, South Africa

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Abstract
Despite their large body size and high abundance, the Spirostreptidae are amongst the poorly studied invertebrate groups in southern Africa. Field observations of behaviour, such as movement and burrowing are uncommon. As such, field observations of walking speed, movement patterns and burrow shape of *Spirostreptus heros* Porat, 1872 were made. Surface type and vegetation cover influenced the speed and pattern of walking in *S. heros*. Walking speed ranged from 0.66 to 2.38 m/min on loose and compact sand without vegetation, and on surfaces with vegetation. Walking speed was significantly different among the three surface types ($p < 0.005$), but not between sexes. Inferences are made on the adaptive significance of walking fast in a harsh environment. Additionally, the golf club-shape or J-shape and depth (mean 22.71 cm) of burrows of *S. heros* are herein described for the first time.

Keywords: Millipede, detritivores, walking, burrows, soil

1. Introduction
Mobility in millipedes is critical in finding unevenly distributed food sources and mates [1]. As such, walking is the most common behaviour in millipedes [2]. When millipedes are not walking, eating or mating, they find shelter or burrow in response to moisture and temperature stress [3]. In southern Africa, millipedes are thought to burrow to depths of up to 30 cm [1]. However, burrow morphology is poorly known [4] and data from field observations are not available despite the ecological importance of millipedes as detritivores [5] and soil engineers [6].

According to Golovatch and Kime [5] the Kalahari is one of the harshest deserts where millipedes occur. Thus, the burrowing habit allows spirostreptid millipedes species to escape extreme conditions [7]. *Spirostreptus heros* Porat, 1872 is a millipede whose large body size suggests greater ecological role and potential to disperse widely. However, behavioural or ecological data based on field observations *on S. heros* are scarce. As such, walking patterns were observed, walking speed was recorded on different surface types and depth of burrows was measured and the shape determined in the field.

2. Materials and Methods
2.1 Study Area and time of sampling
The study was undertaken at Witdraai farm, Andriesvale (26^0 57' S, 20^0 45' E), in the Kalahari Desert, Northern Cape Province, South Africa, in 2011. Observations were recorded 24 hours after a rainfall event at the end of April — the last weeks of millipede surface activity before the onset of winter and dry conditions. Observations were between 07h00 and 18h30 along six 100 m long X 5 m wide transects on loose, compact sand without vegetation and on sand with vegetation.

2.2 Data collection and statistical analysis
Walking speed of *S. heros* individuals that were encountered on the three surface types was measured. Observations of individuals were made approximately 50 cm from each specimen. Millipedes that curled up immediately after an encounter or during observations were excluded from the study. A 5 m measuring tape was used to measure distance walked and a stop watch recorded time (seconds).

Observations on each surface type were stopped when the millipede stopped walking or when the surface type along transects changed. After each observation, the sex of the specimens was determined, and the body length and maximum body diameter were measured using a string and a 30 cm ruler, and Vernier calipers, respectively.Ten voucher specimens (including mating pairs) were taken to the laboratory for identification. The specimens were deposited in the KwaZulu-Natal Museum, Pietermaritzburg, South Africa. Millipede burrows were identified by the approximately 20 mm wide cylindrical exit holes on the surface. Each burrow was carefully excavated. Because the sandy soil was moist and compact the burrows did not collapse during excavation, thus casting reported in Sinha [8] was not necessary. A garden spade (95 cm long, with a 65 cm long handle and a 30 cm X 21 cm rectangular digging end) was used to slice off small layers (at a time) of the compact sand from one side of the exit hole. Slicing was started approximately 10 cm from each exit hole and continued until the full length of the burrow was exposed. Slicing was done after sand had been removed (to a depth of 30 cm) from one side of the burrow to allow viewing and measurement of the burrow from that side. In order to slice off thin layers of sand, the digging end of the spade was completely pushed into the soil at approximately 90 degrees to the surface. The depth of each excavated burrow was measured using a 30 cm ruler. An independent t-test and analysis of variance were performed on the data.

3. Results

Peak activity (82 % of all observations) was between 08h00 and 12h30. Between 12h30 and 17h00, 98 % of specimens were found in sheltered places, such as, burrows, termite mounds, and tree crevices and under plant litter and man-made structures. Although surface activity increased after 17h00, it was lower than between 08h00 and 12h30.

Walking speed was recorded for 57 adults. The mean walking speed of *S. heros* were 1.84 ± 0.47 m/min (mean ± standard deviation) on loose bare sand (n=17), 2.38 ± 1.06 m/min on compact sand (n=21) and 0.66 ± 0.32 m/min in vegetation (n=19) (Table 1). Differences in walking speed among the three surfaces were significant (ANOVA, $p = 27.00 < 0.005$). However, there was no significant difference in walking speed between the sexes (t-test, $p = 0.764 > 0.05$). Individuals walked faster and straight on bare sand than where there was vegetation. Besides being slower, walking in vegetation had frequent 'detours' and the head was moved from side to side.

Table 1: Walking speed (m/min) of *S. heros* on three types of sand surfaces in the Kalahari Desert, South Africa

Type of sand surface	n	Mean walking speed (m/min) ± SD
Loose bare sand	17	1.84 ± 0.47
Compact bare sand	21	2.38 ± 1.06
Sand with vegetation	19	0.66 ± 0.32

Surface active *S. heros* fed on goat faecal material, millipede faecal pellets, flowers, the Kalahari melon (known to locals as *tsamma*), a wild cucumber, leaf litter, Acacia pods and bark, and the leaves and bark of the devil's claw, *Harpagophytum procumbens* DC. Ex Meisn, which was cultivated at the farm. Adult body length was between 150 and 240 mm and maximum diameter between 12 and 20 mm.

Millipedes were found in 72 % of the burrows that were on the edges of cultivated sites and close (< 15 cm) to food items, such as, mammalian faecal matter and wild fruits.

Excavated burrows (n=13) of *S. heros* were golf club-shaped or J-shaped, with an almost vertical cylindrical shaft and a wide basal chamber large enough to accommodate a curled-up millipede. The mean depth of burrows was 22.71 ± 1.60 cm (Fig. 1). Assuming that individuals found in the burrows had made them, the depth of the burrows of *S. heros* did not differ between sexes ($p = 1.60 > 0.05$).

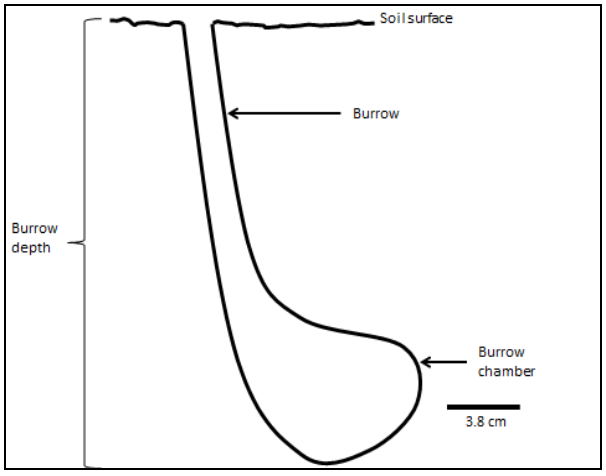

Fig. 1: Burrow of S. heros

4. Discussion

S. heros was less active and hid in sheltered places in the afternoon to avoid high temperatures and reduce the risk of desiccation. Golovatch and Kime [5] reported that basking and hiding in cool areas are behavioural strategies for thermoregulation in desert millipedes. Observed activity of *S. heros* corroborates Dangerfield and Kaunda [2] who reported early morning and late afternoon peaks in surface activity of tropical millipedes.

There was no significant difference in walking speed between the sexes, thus the notion that males are faster than females because they have longer legs [9] is not supported. Walking faster and straight on bare sand facilitates finding food and suitable habitats sooner. Such a tactic presumably reduces the risk of desiccation in direct sunlight and lowers the risk of predation. Fast directional movement in millipedes could also be a strategy to find resources that are scarce and far apart [2]. In vegetation walking was slower probably because barriers, potential shelter sites and food items were encountered. Being large, *S. heros* walked quickly. Large species have better dispersal ability than smaller species [10]. According to Mwabvu and Schoeman [11] *S. heros* has the largest potential habitat space than smaller-bodied congenerics because it has a larger body size. Given that millipedes are opportunistic feeders Dangerfield and Telford [12], greater mobility of *S. heros* allows faster migration between habitats in search of suitable resources. This is consistent with Dangerfield's [13] observation of millipedes moving between cultivated plots and natural vegetation. Unfortunately, comparable field observations of movement in other tropical millipedes are absent.

Burrowing allows millipedes to escape harsh conditions, such as extreme temperatures in the Kalahari Desert [7]. Besides being an adaptation to extreme conditions, burrowing near food items by *S. heros* is probably a strategy to reduce

foraging costs in an environment in which food availability is variable and unpredictable [14]. In support, another tropical millipede, *Doratogonus uncinatus Attems*, 1914 was reported to burrow into food of higher quality after a feeding bout [15]. As such, that *S. heros* burrowed near food sources partly explains the burrows around the cultivated sites at Witdraai farm. The presence of burrows at the edges of cultivated sites suggests that millipedes could emerge to feed on cultivated plants when environmental conditions are favourable.

Similar J-shaped burrows made by some ground beetles [16] and other millipedes [4] have been reported. The depth of burrows is influenced by soil moisture levels [14]. In the Kalahari soil moisture levels are likely to be influenced by time of day, exposure to sunlight, time after a rainfall event and the amount of rainfall received. As such, depth of *S. heros* burrows may vary (within limits for the species) depending on the soil conditions.

Movement and burrowing ability of *S. heros* has implications for their role as ecosystem engineers. Hence, there is much to gain by investigating the influence of extrinsic factors on activity and burrow architecture of millipedes in the Kalahari Desert, where large numbers are active for short periods at a time.

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