MONITORING TENEBRIONID BEETLE BIODIVERSITY IN NAMIBIA

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ABSTRACT Different field methods of determining abundance and species diversity of darkling beetles (Coleoptera, Tenebrionidae) were tested. A combination of the use of pitfall traps and linear transect surveys served as the best rapid assessment of diversity, while pitfall traps alone are good for estimating abundance. Trap size (15cm diameter vs. 10cm diameter) and different degrees of exposure to sun did not significantly affect the capture rate of beetles, which was highly variable between traps at a site, but there were differences between sites and seasons. A minimum of a full year of trapping is required before the slope of the species-effort curve begins to flatten when the most abundant species have been recorded. The curve continues to increase over the course of the next 20 years, by which time all species at a location have been recorded. Furthermore, long trapping periods covers different climatic conditions, reflecting that in the Namib Desert, long-term records are required to study biodiversity.

Key Words: Namib Desert; Darkling beetles; Pitfall traps; Trap size; Species-effort curve.

INTRODUCTION

Beetles play significant roles in most ecosystems (Ehrenfeld, 1988). Prominent epigeal examples are the Tenebrionidae that play a relatively major role in tropical and subtropical drylands, more so with increasing aridity. These beetles are important macro-detritivores that play an important role as primary decomposers (Crawford, 1979).

Tenebrionids are relatively abundant, large, apterous, cursorial, readily captured in pitfall traps, and most are easily identified. In southern Africa most are detritivores with variable tendencies for omnivory. Communities of these beetles integrate factors such as the availability of detritus, plant cover and various soil characteristics, such as moisture, hardness, and grain size composition. These factors differ for different species and for eggs, larvae and imagines. We therefore expect tenebrionid to be sensitive indicators of biodiversity change along natural and anthropogenic gradients in dryer parts of southern Africa (Parenzee, 2001). Long-term monitoring of their populations can provide valuable insights into how environmental changes affect organisms (Henschel et al., 2003).

In the current study, we compare different methods of monitoring abundance and species diversity of tenebrionid beetles in order to improve future analyses. We first compare direct visual searches with pitfall trapping conducted in the same area. In a set of tests, we compare two sizes of pitfall traps that are in common use in our studies. Furthermore, we compare traps located in different microhabitats, namely, exposed in the open, and sheltered (shaded). We then analyse how the number of species recorded increases with the number of pitfall traps, and how progressively more species are captured over years. Our study will facilitate analyses of future data of beetle diversity recorded with these methods.

METHODS

I. Pitfall Traps

We used two kinds of pitfall traps. The Gobabeb standard trap (Henschel et al., 2003) has a 15cm diameter, and the traps are either plastic or metal buckets of 20cm depth. The BIOTA standard trap has a 10cm diameter. It is made of a vertical plastic drain pipe into which the 20cm straight, bottom half of a plastic bottle is inserted. We used both types of traps in different parts of the study and compared them in one test. The BIOTA standard trap was fitted with a lid of 15cm diameter propped up two fingers above each trap that allows passage of beetles. Unless stated otherwise, our BIOTA traps were kill-traps, using monoethylene glycol as preservative and all other traps were live traps emptied daily.

II. Species Identification

Animals were preserved in 70% alcohol. A reference collection is kept to facilitate identification. Voucher specimens were pinned and compared with collections of the National Museum of Namibia. Where possible, tenebrionids were identified to species level, else morphospecies designations were used. In the current study, the number of species in a data set refers to the total of identified species plus morphospecies.

III. Beetle Capture Method

Daily captures in pitfall traps were compared with direct observations in the field. Fieldwork was conducted between 12 and 19 September 1997 near the Richtersveld National Park, South Africa, at four sites: (1) Beauvallon; (2) Beesbank; (3) Noemees; and, (4) Grasdrif. Three sets of three Gobabeb standard live pitfall traps without lids were deployed in the early mornings and were emptied and removed a day later. Observations were made by a single person walking for 2 hours starting about 2 hours after sunrise over a distance of 1km southwards and 1km northwards parallel but 100m distant from the previous track. All active beetles, and separately all dead beetles of species not previously seen in other sets, were collected along the census line.

IV. Effect of Pitfall Trap Size, Microhabitat, Location and Season

Four study sites were located in different climatic zones of the Central Namib Desert reaching from the coast to the Namibian highlands (Besler, 1972; Hachfeld, 2000). These were: (1) Kleinberg, located in the cold foggy coastal plains with extremely rare rainfall in either winter or summer; (2) Gobabeb, in the cool to warm foggy plains with rare rainfall; (3) Ganab, in the warm inland desert plains with occasional summer rain; and, (4) Rooisand, located at the arid escarpment that gets annual summer rains.

During the long-term pitfall trapping project conducted inside the Namib-Naukluft Park near Gobabeb (Henschel et al., 2003), pitfall traps with a diameter of 15cm are used. When BIOTA monitoring was initiated in agricultural areas it became apparent that smaller plastic pitfall traps of 10cm diameter would be less susceptible to human and animal disturbance. To validate the use of the smaller traps, we compared the capture efficiency of these two trap types.

The microhabitat where a pitfall trap is placed at a location may influence the number of beetles trapped. For instance, beetles may occur under shelters where the microclimate is less extreme and may occur in open areas when foraging during mild times of day or when moving to other shelters. To test the effect of shelter, we compared sheltered places with open ones.

Trap size and shelter were tested by deploying three types of pitfall traps, namely, large (15cm) Gobabeb standard traps with lids in open microhabitat (**O**), small (10cm) BIOTA standard traps with lids in the open (**o**), and the same small type at a sheltered site (**s**). Traps of each **O-o-s** set were placed 20m apart in a triangle in the southern half of BIOTA Observatories (Krug et al., 2006). At each BIOTA Observatory in the Central Namib, we deployed sets of traps in 6 hectares. In these 6 hectares, the different habitat types of the Observatory are represented at least once, with more hectares randomly chosen in the more common habitats. Traps were kept in the field for periods of one month during February and June 2005. At Rooisand warthogs disturbed some traps resulting in 26% loss of trapping effort. A total of 103 samples were analyzed with ANOVA and Tukey post-hoc test. Individual sets were compared with t-test and pairs (**O-o**, **o-s**) with the sign test.

V. Number of Pitfall Traps

The number of pitfall traps used may affect the number of species recorded at a site. To explore this, we used the above data from the Central Namib BIOTA Observatories for February and June 2005 and treated traps **O**, **o** and **s** as replicates (8 sets of 18 traps). We calculated the cumulative number of species in successive traps for each set, and repeated this 18 times starting with different traps. The mean for each sequence number was used to compile a species-effort curve. The two seasons from each site were examined cumulatively, i.e. only species not recorded in February were added in June.

VI. Duration of Trapping

The duration for which pitfall trapping is conducted may affect the number of species recorded at a site. Longer trapping may record seasonally active species, or event-driven population irruptions (e.g., after rainfall), rare species, or dispersing individuals from a nearby population. Long-term continuous pitfall trapping since 1976 at two sites near Gobabeb (Henschel et al., 2003) enabled us to examine over which time period species were first recorded at a particular site, and what the final relative abundance of these species was. Continuous live-trapping was conducted with 15 Gobabeb standard traps without lids on the gravel plains 2km north of Gobabeb, and with 25 traps on the interdune plains 2km south of Gobabeb. Traps were monitored and emptied three times per week.

RESULTS

I. Beetle Capture Method

The total number of species recorded in two hour surveys in the Richtersveld yielded a similar number of species as did one day of pitfall trapping with nine traps (Table 1). At least 12–44% additional species were observed being active than were captured in pitfall traps. Sightings of dead beetles increased the number of recorded species by 0–29% (Table 1), perhaps including species that may not be active during the survey season. An average of 4.27 individuals was captured per trap per day compared to $6.12.hr^{-1}$ live beetles observed.

II. Effect of Pitfall Trap Size, Microhabitat, Location and Season

Captures were compared in pitfalls of different size (15cm and 10cm, **O** vs **o**), deployed in different microhabitats (open and sheltered, **o** vs **s**) at four locations (Kleinberg, Gobabeb, Ganab and Rooisand) for one month periods during February and June 2005. The number of tenebrionid beetles captured per trap per month ranged from 0 to 706 (mean=33.2 ± sd87.1, n=138) with up to 12 species per trap (mean=2.7 ± sd2.3). Tenebrionid abundance per trap differed significantly with location ($F=10.606$, $df=3$, $p<0.001$) (Fig. 1), Rooisand having significantly higher abundance than the other sites (Tukey post-hoc test: $q>6.347$, $p<0.001$). The same was true for the number of species (location: $F=7.017$, $p<0.001$; $q>4.207$, $p<0.019$) (Fig. 2). There was also a significant

Table 1. Abundance and number of species of tenebrionid beetles recorded in one day at different places in the Richtersveld using different methods (brackets indicate the number of species unique to that method).

	Abundance				Number of species			
Place	Total	Pitfall traps	Census	Dead	Total	Pitfall traps	Census	Dead
Beauvallon	103	94	6	3	11	7 (3)	4 (1)	3 (3)
Beesbank	25	11	12	2	11	7 (4)	4 (2)	2 (2)
Noemees	47	26	17	4	14	6 (3)	7 (4)	4 (4)
Grasdrif	37	23	14	0	9	5 (1)	8 (4)	0 (0)

* Dead beetles represent species not previously seen in other sets.

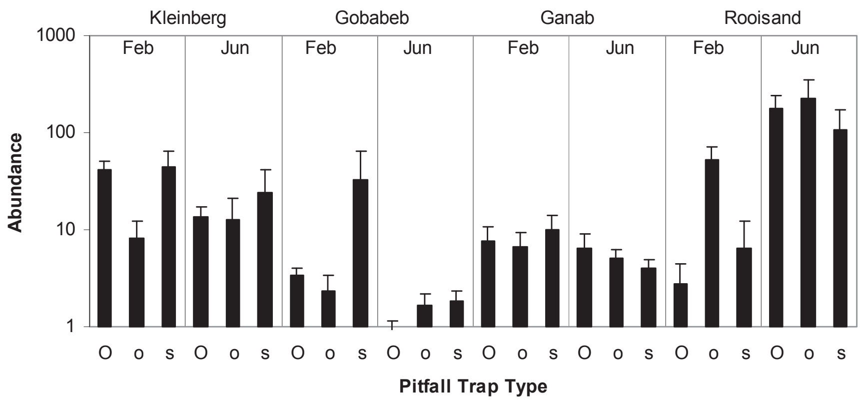

Fig. 1. Abundance (log scale, mean ± 2se, n=6) of tenebrionids captured in individual pitfall traps of different types (**O**=large in open; **o**=small in open; **s**=small in shelter) deployed for 1 month during February or June 2005 at four locations.

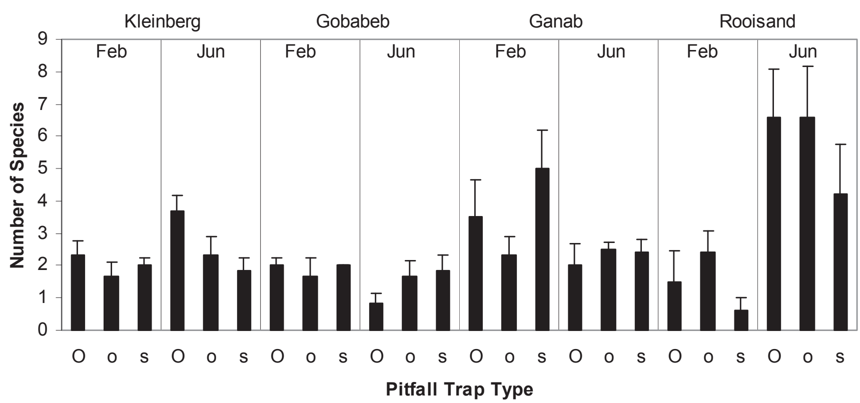

Fig. 2. Number of species (mean ± 2se, n=6) of tenebrionids captured in individual pitfall traps of different types (**O**=large in open; **o**=small in open; **s**=small in shelter) deployed for 1 month during February or June 2005 at four locations.

effect of season (abundance: F=5.983, df=1, p=0.016; species number: F=6.175, p<0.014), but the direction of change differed between sites (Figs. 1 & 2).

There was no significant effect of trap size and microhabitat (F=0.334, df=2, p>0.717). At closer examination of trap pairs differing in size (**O** vs **o**) in each season at each location, we detected significantly more beetles in the larger traps only at Kleinberg in February (paired t-test: t=4.166, df=5, p=0.004). The number of species captured did not differ significantly in any set (t-test, p>0.05) (Fig. 2). Furthermore, overall comparison of all **O-o** data pairs revealed no significant difference in abundance and number of species (pair sign test: p>0.711). Similar tests with **s-o** data pairs did not reveal any significant differences in beetle abundance and number of species (Figs. 1 & 2).

III. Number of Pitfall Traps

Each species-effort curve for a monthly data set from four BIOTA Observatories across the central Namib had a negative exponential shape. This started with high probability of recording additional species with the first 3–4 traps and a lower probability for the later traps. The result illustrated for Ganab (Fig. 3) was broadly similar to that of the other sites.

Always more than 50% of the new species recorded in each trapping session were found in the first 3–7 of 18 traps, followed by a more gradual accumulation in the remaining traps. During February, the rate of trapping new species did not level off completely at any site. This was because of species with a low probability of capture, e.g., rare species, some of which occurred in only one trap (singletons). During June, the species-effort curve finally levelled off at Kleinberg and Gobabeb, sites where there were no singletons (Table 2). By

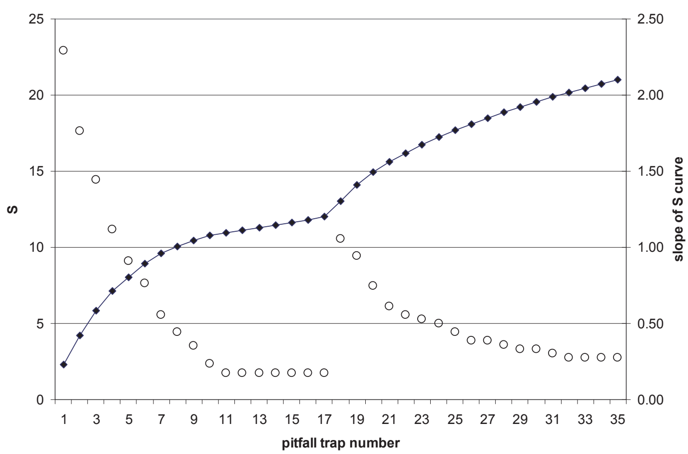

Fig. 3. Species-effort curve (cumulative number of species vs cumulative number of traps) at the Ganab Observatory for pitfall traps 1–17 during February and traps 18–35 during June 2005.
*Circles = mean number of new species for each successive trap in the sequence; Diamonds = cumulative number of species.

Table 2. Number of new species (spp.) captured at different locations during different months, number of singletons recorded (species found in only one trap), mean number of new species in the first and last traps of February and June.

	Feb	Jun	Feb	Jun	Feb	Feb	Jun	Jun
Location	total new spp.	total new spp.	singletons	singletons	new spp. first trap	new spp. last trap	new spp. first trap	new spp. last trap
Kleinberg	12	4	8	0	2	0.39	0.67	0
Gobabeb	8	2	2	0	1.94	0.06	0.26	0
Ganab	12	9	3	5	2.29	0.18	1.06	0.28
Rooisand	11	13	5	5	1.5	0.29	2.26	0.29

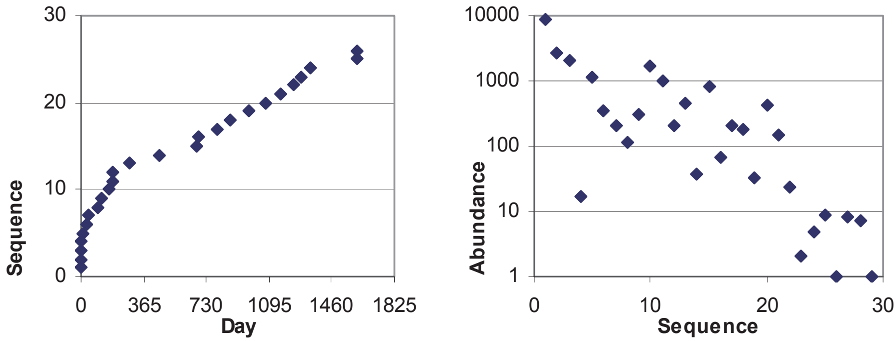

Fig. 4. Day of first capture in 15 pitfall traps of different species on the Gravel Plains over the course of 5 years, indicating the sequence number of newly recorded species and the total abundance of these species recorded during 25 years.

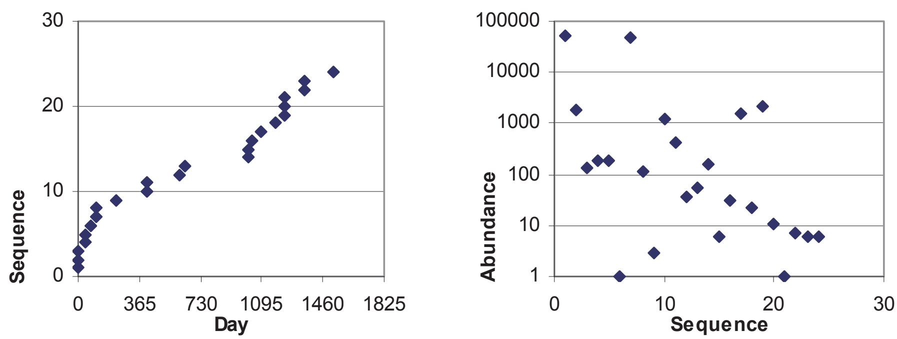

Fig. 5. Day of first capture in 25 pitfall traps of different species on the Interdune Plains over the course of 5 years, indicating the sequence number of newly recorded species and the total abundance of these species recorded during 25 years.

contrast, there remained a probability of recording new species until the last trap at Ganab and Rooisand (Table 2).

IV. Duration of Trapping

At both long-term study sites at Gobabeb, the gravel plains and interdune plains, it tended to take longer for less abundant species to be first recorded (Rs=-0.689, df=26, p<0.001; interdune: Rs=-0.459, df=24, p<0.025) (Figs. 4 & 5). On the gravel plains six species were recorded during the first month, and another six species during the next five months of trapping at an average rate of a new species first identified every 25 days (Fig. 4). Thereafter the next 14 species were first recorded in the course of the next four years at a rate of one every 101 days. The pattern of first recording species in the interdune plains (Fig. 5) was broadly similar. Five species were recorded in the first month, and another 3 species during the next two months, followed by a reduced rate of one every 88 days for the next 16 species over four years. Even after five years, the species lists were not complete in both habitats and 3–5 additional species were first recorded during the course of the following 18 years. However, the latter species were rare at the particular study sites.

DISCUSSION

Pitfall traps were first described by Barber (1931) and are a convenient method of catching some kinds of epigeal arthropods. The number of trappable animals actually captured may depend on the population density, activity pattern, walking speed, and small area distribution of particular species (Mitchell, 1963). On annual time scales, short-term activity patterns make no difference and trapping can reliably reflect the population density of epigeal arthropods that move independently of each other (Jansen & Metz, 1979).

Pitfall traps can, however, have drawbacks. The probability of capture may depend on duration of activity, distance moved and home range, which differs between species. Some species avoid or are attracted to traps (Mitchell, 1963; Luff, 1975; Digweed et al., 1995). Male tenebrionids following females (Polis et al., 1998) violate the assumption of independent movements. Furthermore, it is difficult to translate pitfall captures into population density (but see Gist & Crossley, 1973). Pitfall traps are unreliable to determine diversity of some animals, like ants (Marsh, 1984; Brühl et al., 1999), or wandering spiders (Henschel, 1991) that detect and avoid pits or climb out of them.

Nevertheless, in field studies, pitfall traps have been considered reliable for beetles (Mitchell, 1963; Greenslade, 1964; Rickard & Haverfield, 1965; Luff, 1975; Baars, 1979; Ericson, 1979; Faragalla & Adam, 1985). Namib tenebrionids are easily trapped and cannot escape from live-traps. Our present use of pitfall traps is consistent with previous use in studies of Namib tenebrionid ecology (e.g., Holm & Scholz, 1980; Wharton & Seely, 1982; Crawford & Seely, 1987;

Henschel et al., 2003).

I. Beetle Capture Method

In combination, the three methods, namely, pitfall traps, and censuses of live and dead animals, serve as a more rapid assessment of species diversity than any method alone. However, pitfall trapping is the better method to investigate relative abundance, particularly over long periods of time. This is similar to findings of Lindsey & Skinner (2001), who detected most ant species using pitfall traps in comparison to sampling from quadrats or by digging, but suggested that different methods should be used in combination. Using pitfall traps, it is also possible to detect species active at different times of the day. For instance, at Beauvallon, 79 *Stips* sp. were captured in pitfall traps, representing 77% of the catch, while this nocturnal tenebrionid (Wharton, 1983) was completely absent during the diurnal census.

II. Effect of Pitfall Trap Size, Microhabitat, Location and Season

Trap diameter was expected to affect the probability of capturing insects. Work et al. (2002) collected more carabid species in traps with a 15cm diameter mouth than in smaller 11cm traps. However, in our study, the numbers actually captured in individual traps was highly variable, and there were no significant differences between trap sizes. While Melbourne (1999) showed a significant relationship between the species number of ants in pitfall traps and habitat structure, vegetation structure affected the trapability of some carabids in opposite ways but it did not affect others in the study of Koivula et al. (2003). Likewise, our expectation of differences between shaded and exposed sites was not confirmed by our data. Rather, location in different climatic zones affected the number of individuals and number of species captured in a trap, and there were also seasonal effects. Data sets from longer periods will be required to elucidate the overall effects of location and time.

III. Number of Pitfall Traps

The rapid decline of the species-effort curve in each month (Fig. 3) indicates that 18 traps sufficed to adequately sample a location during a given month. However, the increment of new species in a new month and the gradual continuation of recording new species at these locations indicate that trapping must be continued for more months in order to estimate the overall local diversity.

IV. Duration of Trapping

For tenebrionids, a rapid assessment based on a single intensive sampling cannot easily reveal the diversity. It takes about a year of continuous trapping event to record the most abundant species, while more rare species require sustained effort. The species-effort curves did not level off even after four to five years with 25,000 to 40,000 trap days and only after 20 years of continuous trapping new species were no longer recorded for the next five years. This may be due to the difficulty of detecting rare species or "tourists" wandering through an area from another habitat. However, long-term trapping also covers different climatic conditions, for instance rainfall, which affects the activity of different species (Seely et al., 2005). The implications for our study are that long-term trapping is required to understand the biodiversity and community composition of this important insect group.

CONCLUSIONS

The greatest power of expression of the results we can obtain from pitfall traps lies in the relative abundance and number of species of tenebrionids caught over space and time. Nevertheless, even in this respect they may indicate changes within each group and enable qualitative comparisons between groups. Our study validated the number and size of pitfall traps employed. Pitfall trapping and population responses make tenebrionids a convenient and suitable taxon to track environmental conditions over long periods of time.

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