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SOIL PREFERENCES OF TIGER BEETLES IN SELECTED LOCATIONS OF SRI LANKA

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ABSTRACT

Tiger beetles are terrestrial insects that are worldwide in distribution. Species are highly habitat specific and therefore vulnerable to changes in the habitat. Habitats and distribution of tiger beetles are associated with the soil of the location as larvae are soil dwelling and oviposition site selection by females is based on soil characteristics. We report soil characteristics of the habitats of tiger beetles in selected locations of Sri Lanka and soil preferences of different species. Ninety-four locations of Sri Lanka were investigated for tiger beetles and beetles were collected from thirty-seven locations. Species were identified using standard keys and comparison with type specimens. Soil group, soil type, soil colour, soil pH, soil moisture, soil temperature and soil salinity of tiger beetle collection locations were determined using standard methods. Ten species of tiger beetles occupied soils with a sandy texture and yellowish and reddish brown colour. Soil temperatures ranged from 27.5°C to 38.5°C. Different tiger beetle species displayed specific preferences to soil group, soil pH, soil moisture and soil salinity. *Hypaetha biramosa* was found on saline soils with alkalinity of the "Regosols on recent beach sand" soil group. *Calomera angulata* and *Myriochila* (*Monelica*) *fastidiosa* occurred on "Reddish Brown Earths". *Calomera angulata* and *Lophyra* (*Lophyra*) *catena* preferred significantly low soil moistures while *Cylindera* (*Ifasina*) *labioaenea* preferred soils with high soil moistures which were slightly acidic. *Cylindera* (*Ifasina*) *labioaenea* and the majority of tiger beetle species occurred on Alluvial soils and Red-Yellow Podzolic soils.

INTRODUCTION

Tiger beetles (Coleoptera, Cicindelidae) are a group of ground living predatory insects that are found in a range of habitats such as beaches, salt flats, river banks, grasslands, dirt roads and agricultural lands. These habitats differ greatly in physical structure, soil characteristics and plant composition but share the presence of bare patches of open ground which they require for foraging and oviposition (Knisley 2011, Cornelisse *et al.* 2013). Female tiger beetles are specific in choosing oviposition sites as larval stages are soil-dwelling, long-lived and sedentary, and sites are selected based on conditions of soil moisture and structure (Brust *et al.* 2006, Cornelisse and Hafernik 2009). Therefore, the type of the soil is important for larval development and for the survival of tiger beetles and may determine their distribution, habitat types and abundance.

Fifty-nine species of tiger beetles have been reported from Sri Lanka of which thirty-nine species are endemic (Horn 1904, Fowler 1912, Naviaux 1984, Acciavatti and Pearson 1989). However, most species have not been recorded since 1989, and their distribution, habitat types and habitat preferences have not been investigated. As Sri Lanka is a developing country with increasing pressure on natural habitats, it is necessary that the group be studied and included in the biodiversity conservation efforts in Sri Lanka. The present study intends to investigate the soils occupied by tiger beetles of Sri Lanka and soil preferences of different tiger beetle species. The findings will assist in predicting the distribution of tiger beetle species within various habitat types of Sri Lanka.

METHODOLOGY

Survey and collection of tiger beetles

The survey for tiger beetles was conducted in 94 locations in the country, from May 2002 to December 2006. The localities for collecting tiger beetles were selected using information based on previous publications of cicindelid species of Sri Lanka and information based on the different habitat types of the

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family on a global scale. Coastal areas, river banks, reservoir banks, agricultural lands, marshlands and urban areas in the wet, intermediate and dry zones were included in the survey. These sites were closely examined for tiger beetles and when encountered a sample of 3 to 5 beetles were collected from each site, using a standard insect net. Specimens were preserved and stored in 70% alcohol for identification.

Identification of tiger beetles

Tiger beetles were identified using keys for *Cicindela* of the Indian subcontinent (Acciavatti and Pearson 1989) and descriptions of Horn (1904), Fowler (1912) and Naviaux (1984). Identifications were confirmed by comparing the specimens with type specimens available in the National Museum of Colombo, Sri Lanka and British Natural History Museum of London, United Kingdom. Nomenclature is based upon Wiesner (1992) except for the use of the generic name *Calomera* instead of *Lophyridia*, based upon Lorenz (1998).

Determination of soil parameters

The following parameters of soil in the sampling locations of tiger beetles were determined using the method stated.

(i) Soil group: determined using the generalized soil map of Sri Lanka;

(ii) Soil type: determined by the sedimentation technique using the "soil textural triangle";

(iii) Soil colour: measured by comparison with a Munsell soil colour chart (Year 2000 revised edition);

(iv) Soil temperature: measured using a soil thermometer (SG 680-10);

(v) Soil pH: measured using a portable soil pH meter (Westminister No. 259);

(vi) Soil moisture: determined by collecting five random samples to a depth of 10 cm and estimating the difference in fresh weight upon oven drying to 107-120°C in the laboratory;

(vii) Soil salinity: measured using a YSI model 30 hand-held salinity meter.

Statistical analysis

The data on soil parameters of the locations of different tiger beetle species were analyzed using One-Way Analysis of Variance and Tukey's multiple comparison method using Minitab 16.0 statistical software package.

RESULTS

Tiger beetle species and recorded locations

Of the 94 locations surveyed, tiger beetles were encountered in 37 locations comprising coastal, riverine, reservoir and urban habitat types (Figure 1 and Table 1). They were found on sand dunes and beaches of coastal areas, banks of rivers and reservoirs and on bare patches of land in urban areas. Ten species of tiger beetles representing five genera were identified from the different locations (Table 1).

Table 1. Tiger beetles recorded from different survey locations (Location number coincides with the number given for the location in Figure 1)

	Survey location and habitat	Species recorded
1.	MahakanadarawaWewa, Anuradhapura district; Reservoir bank	*Calomera angulata*
2.	Nuwara Wewa, Anuradhapura district; Reservoir bank	*Myriochila (Monelica) fastidiosa*
3.	Thisa Wewa, Anuradhapura district; Reservoir bank	*Calomera angulata*
4.	Nachchaduwa Wewa, Anuradhapura district; Reservoir bank	*Calomera angulata* *Myriochila (Monelica) fastidiosa*
5.	Tabbowa Wewa, Puttalam district; Reservoir bank	*Calomera angulata* *Myriochila (Monelica) fastidiosa*
6.	Kala Wewa, Anuradhapura district; Reservoir bank	*Calomera angulata*
7.	Kandalama Wewa, Matale district; Reservoir bank	*Calomera angulata* *Myriochila (Monelica) fastidiosa*
8.	Parakrama Samudra, Polonnaruwa district; Reservoir bank	*Calomera angulata*
9.	Devahuwa Wewa, Matale district; Reservoir bank	*Lophyra (Lophyra) catena* *Calomera angulata* *Cylindera (Oligoma) lacunosa*
10.	Batalagoda Wewa, Kurunegala district;	Reservoir bank *Calomera angulata*
11.	Halawatha coastal area, Puttalam district;	Sand dunes *Lophyra (Lophyra) catena*
12.	Ma Oya, Alawwa, Kurunegala district;	River bank *Calomera angulata* *Calomera cardoni*
13.	We Oya, Yatiyantota, Kegalle district;	River bank *Cylindera (Ifasina) labioaenea*
14.	Maha Oya, Dehi Owita, Kegalle district;	River bank*Cylindera (Ifasina) willeyi*
15.	Maha Oya Falls, Dehi Owita, Kegalle	district; Moist rocks *Cylindera (Ifasina) labioaenea*
16.	Seethavaka River, Colombo district; River bank	*Cylindera (Ifasina) labioaenea*
17.	Aswathu Oya, Colombo district; River bank	*Cylindera (Ifasina) labioaenea*
18.	Heen Ela, Waga,Colombo district; River bank	*Cylindera (Ifasina) labioaenea*
19.	Kelani River, Malwana, Gampaha district; River bank	*Cylindera (Ifasina) labioaenea*
20.	Kelani River, Kirielamulla, Gampaha district; River bank	*Cylindera (Ifasina) labioaenea*
21.	Kelani River, Kaduwela, Colombo district; River bank	*Cylindera (Ifasina) labioaenea*
22.	Biyagama, Gampaha district; River bank	*Cylindera (Ifasina) labioaenea*
23.	National Museum Garden, Colombo district; Bare land	*Cylindera (Oligoma) paradoxa* *Lophyra (Lophyra) catena*
24.	Angoda home garden, Colombo district; Bare land	*Cylindera (Ifasina) labioaenea*
25.	Wak Oya, Thummodara, Colombo district; River bank	*Cylindera (Ifasina) labioaenea*
26.	Water Canal, Handapangoda, Kalutara district; River bank	*Cylindera (Ifasina) willeyi* *Cylindera (Ifasina) waterhousei*
27.	Bopath Ella, Ratnapura district; River bank	*Cylindera (Ifasina) waterhousei*
28.	Katukurunda coastal area, Kalutara district; Coastal area	*Lophyra (Lophyra) catena*
29.	Aluthgama coastal area, Kalutara district; Coastal area	*Lophyra (Lophyra) catena*
30.	Induruwa coastal area, Galle district; Beach	*Hypaetha biramosa*
31.	Kosgoda coastal area, Galle district; Beach	*Hypaetha biramosa*
32.	Morampitigoda coastal area, Galle district; Beach	*Hypaetha biramosa*
33.	Habaraduwa coastal area, Galle district; Beach	*Hypaetha biramosa*
34.	Matara coastal area, Matara district; Beach	*Hypaetha biramosa*
35.	Ridiyagama Wewa, Hambantota district; Reservoir bank	*Lophyra (Lophyra) catena*
36.	Hambantota coastal area, Hambantota district; Coastal area	*Myriochila (Monelica) fastidiosa*
37.	Kirinda coastal area, Hambantota district; Coastal area	*Lophyra (Lophyra) catena*

Soil parameters

The determined parameters of soil from the survey locations of different tiger beetles are given in Table 2. Soil group, soil pH, soil moisture and soil salinity significantly differed among the locations from which different tiger beetle species were collected. In contrast, the soil type, soil colour and soil temperature did not vary significantly (Table 2).

Significant preferences to different soil groups were found in certain tiger beetle species, where *Hypaetha biramosa* preferred "Regosols on recent beach sand" and, *Calomera angulata* and *Myriochila* (*Monelica*) *fastidiosa* preferred Reddish Brown Earths. The remaining species mainly occurred on soils of the Red-Yellow Podzolic group. Soil pH was significantly high (7.82 ± 0.16) in locations where *Hypaetha biramosa* was encountered than that of the locations of other species ($p<0.05$). In contrast, locations where *Cylindera* (*Ifasina*) *labioaenea* was found had a significantly lower soil pH (5.85 ± 0.45) ($p<0.05$) reflecting acidic soils. Further, the river bank locations of *Cylindera* (*Ifasina*) *labioaenea* had significantly higher soil moisture (21.20 ± 7.60%). *Hypaetha biramosa* and *Myriochila* (*Monelica*) *fastidiosa* were found on significantly saline soils of which the locations of *Hypaetha biramosa* had soils with a higher salinity than the soils of *Myriochila* (*Monelica*) *fastidiosa*.

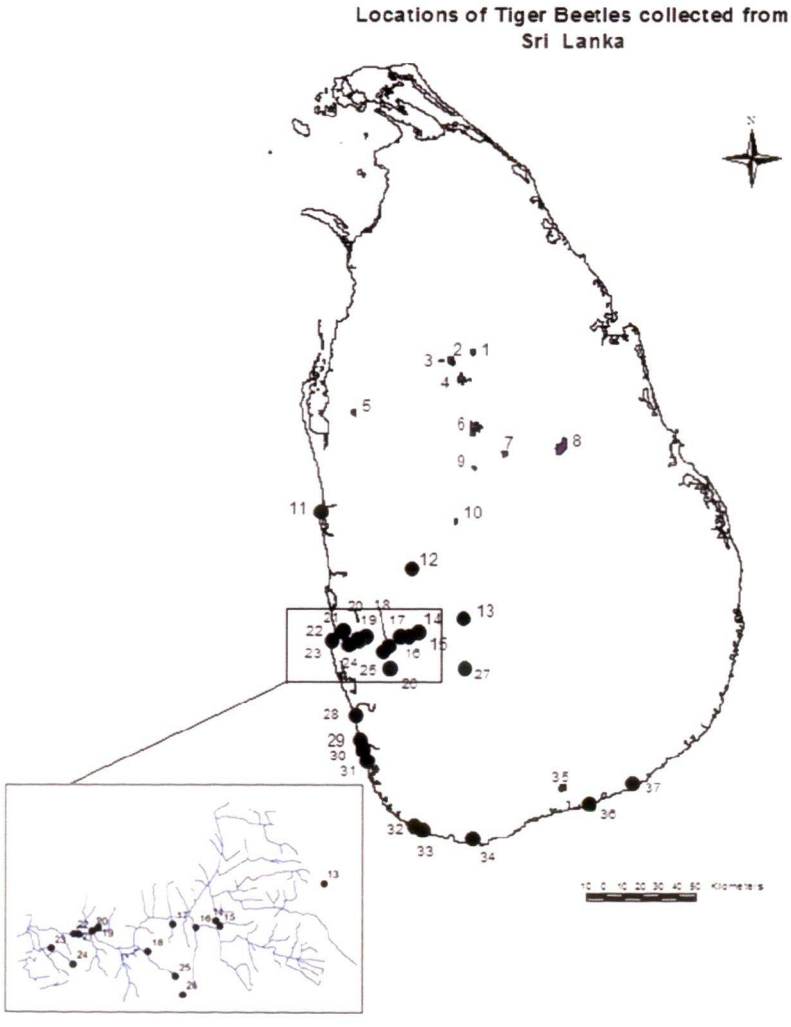

Figure 1. Collection locations of tiger beetles in Sri Lanka

Table 2. Soil parameters in locations of different tiger beetle species (mean and standard error)

Species	*No. of locations recorded from and location numbers*	*Soil Group*	*Soil Type*	*Soil Colour*	*Soil Temperature (° C)*	*Soil pH*	*Soil Moisture (%)*	*Soil Salinity (ppt)*
Hypaetha biramosa	*05 (30,31,32,33, 34)*	*Regosols on recent beach sand*[a]	*Sandy*[a]	*Reddish yellow to brown*[a]	*34.00*[a] ± *0.00*	*7.82*[a] ± *0.16*	*5.97*[a] ± *2.04*	*0.10*[a] ± *0.03*
Lophyra (Lophyra) catena	*07 (9,11,23,28, 29,35,37)*	*Reddish Brown Earth and Regosols on recent beach sand*[b]	*Sandy*[a]	*Black to reddish, yellowish brown*[a]	*34.93*[a] ± *1.25*	*6.88*[b] ± *0.49*	*1.97*[a] ± *1.10*	*0.00*[b] ± *0.00*
Cylindera (Oligoma) paradoxa	01 (23)	Regosols on recent beach sand[b]	Sandy[a]	-	31.50[a]	-	-	0.00[b]
Cylindera (Ifasina) labioaenea	11 (13,15,16,17,18,19,20,21,22, 24,25)	Red-Yellow Podzolic and Alluvial Soils[b]	Sandy, Clay[a]	Yellowish brown to Strong brown[a]	32.44[a] ± 0.71	5.85[c] ± 0.45	21.20[b] ± 7.60	0.00[b] ± 0.00
Cylindera (Ifasina) willeyi	02 (14,26)	Red-Yellow Podzolic[b]	Sandy[a]	Yellowish brown[a]	27.50[a] ± 0.50	6.40[b] ± 0.40	10.43[a] ± 7.54	-

Species	*No. of locations recorded from and location numbers*	*Soil Group*	*Soil Type*	*Soil Colour*	*Soil Temperature (°C)*	*Soil pH*	*Soil Moisture (%)*	*Soil Salinity (ppt)*
Cylindera (*Ifasina*) *waterhousei*	02 (26,27)	Red-Yellow Podzolic[b]	Sandy[a]	Dark yellowish brown[a]	29.25[a] ± 2.26	6.05[b] ± 0.05	10.90[a] ± 7.07	-
Calomera angulata	10 (1,3,4,5,6,7,8, 9,10,12)	Reddish Brown Earth and Low Humic Glay[c]	Sandy[a]	Reddish yellow to yellow, gray, olive shades of brown[a]	33.15[a] ± 1.41	7.10[b] ± 0.17	4.01[c] ± 1.34	0.00[b] ± 0.00
Cylindera (*Oligoma*) *lacunosa*	01 (9)	Reddish Brown Earth[b]	Sandy[a]	Reddish yellow[a]	38.50[a]	6.80[b]	0.13[a]	0.00[b]
Myriochila (*Monelica*) *fastidiosa*	05 (2,4,5,7,36)	Reddish Brown Earth[c]	Sandy[a]	Yellowish to olive brown[a]	32.80[a] ± 0.64	7.18[b] ± 0.21	5.57[a] ± 1.77	0.04[c] ± 0.04
Calomera cardoni	01 (12)	Red-Yellow Podzolic[b]	Sandy[a]	Yellowish brown[a]	29.00[a]	7.10[b]	1.67[a]	0.00[b]

Means sharing a common letter (s) within the same column are not significantly different according to Tukey's multiple comparison test.

DISCUSSION

We report that tiger beetles of Sri Lanka occupy locations with sandy soils that are mainly yellowish brown, brown and reddish brown in colour. The temperature of these soils range from 27.5°C to 38.5°C. We further reveal that different tiger beetle species have specific requirements for soil group, soil pH, soil moisture and soil salinity. Our findings are consistent with a number of other studies that have investigated the soil requirements of tiger beetles (Romey and Knisley 2002, Satoh and Hori 2005, Fenster *et al.* 2006, Cornelisse and Hafernik 2009, Knisley 2011).

Tiger beetles are known to prefer sandy soils to clay and silty soils due to higher egg and larval survival in such soils. The effect of soil compaction that causes reduced soil aeration and moisture is high in clay and silty soils when compared with sandy soils and results in lower egg survival and larval burrow numbers (Cornelisse and Hafernik 2009, Romey and Knisley 2002). Further, sandy soils composed of fine particles facilitate swift running of adult tiger beetles during predation and scavenging (Satoh and Hori 2005). Our findings also revealed tiger beetles from soils with a sandy texture found on banks of water bodies and urban locations. Tiger beetles were not found in locations with clay soils and certain reservoir and river banks investigated had clay soils that were trampled by cattle and elephants.

When considering soil colour, Cicindeline species are known to occur in soils which match their structural colouration. Blending of structural colouration with the colour of the surrounding soil enables tiger beetles to evade attack from natural enemies such as birds, bats and robberflies (Seago *et al.* 2009). As tiger beetles collected during the study were mainly brown and bronze with light yellow elytral maculations and spots, their preference to soils of brown and shades of brown is apparent.

Thus, our findings reveal that tiger beetles require locations with coastal, reservoir, riverine habitats and urban habitats with bare patches of land that have sandy soil with brownish colouration and a specific soil temperature range. However, different species prefer locations with different soil groups, soil pH, soil moisture and soil salinity.

Hypaetha biramosa was restricted to coastal habitats with "Regosols on recent beach" soil group, while *Calomera angulata* and *Myriochila* (*Monelica*) *fastidiosa*, found predominantly in reservoir habitats displayed specificity to Reddish Brown Earths. The other tiger beetle species occupied Alluvial soils and earths composed of Red-Yellow Podzolic soils. The association of different species with different soil groups may reflect a relationship between tiger beetle species and inherent features of the soil group such as soil moisture, soil pH and salinity. Reddish Brown Earths are known to be slightly acidic to neutral and well-drained with a rapid release of soil moisture while Regosols are alkaline with high salinity and rapid infiltration. Alluvial and Red-Yellow Podzolic soils are acidic and non-saline with high soil moisture. *Hypaetha biramosa* restricted to Regosols demonstrated preference for soils with significantly high salinity and soil pH, while *Cylindera* (*Ifasina*) *labioaenea* restricted to Alluvial and Red-Yellow Podzolics displayed preference to significantly high soil moisture and soil acidity. *Calomera angulata* and *Myriochila* (*Monelica*) *fastidiosa* were found in neutral soils of which *Calomera angulata* preferred significantly low soil moisture.

According to studies on the effect of soil pH on tiger beetles, certain tiger beetle species prefer acidic soils for oviposition as acidic soils are devoid of harmful fungi and bacteria that could infect larvae (Cornelisse and Hafernik 2009). We found that most species preferred acidic and neutral soil with *Cylindera* (*Ifasina*) *labioaenea* preferring significantly acidic soils. In contrast, *Hypaetha biramosa* inhabited soils with significantly high pH values that might promote the growth of fungi and bacteria. However, soils of *Hypaetha biramosa* were significantly saline and increased salinity can also negatively affect growth and infectivity of various fungi. Saline soils also inhibit the growth of vegetation producing bare patches of land well exposed to sunlight. Such habitats are suitable for ovipositional and foraging behavior of tiger beetles. Thus, soil salinity is considered as an environmental marker for habitat suitability of tiger beetles, and different species are known to have preferential soil salinity ranges (Brosius 2010). In the present study, *Hypaetha biramosa* and *Myriochila* (*Monelica*) *fastidiosa* preferred soils with salinity ranging from 0 to 0.2 ppt, while the other species preferred non-saline soils.

Soil moisture is required by tiger beetles for larval burrow formation and prevention of larval dessication (Romey and Knisley 2002, Cornelisse and Hafernik 2009). Different species are known to require different percentages of moisture due to their sensitivity to dessication and flooding. Species that are highly sensitive to dessication and flooding are found in locations with a narrow range of soil moisture while species that are least sensitive can tolerate wide ranges (Cornelisse and Hafernik 2009). In the present study different tiger beetle species demonstrated different preferences for soil moisture content, and variations in tolerance ranges were also evident. *Calomera angulata* together with *Lophyra* (*Lophyra*) *catena* preferred locations with significantly low soil moisture with tolerance ranges of 0.12 – 11.49% and 0.13 – 7.93% respectively. *Cylindera* (*Ifasina*) *labioaenea* was found in locations with significantly high soil moisture with a wide tolerance range of 3.198 – 52.21% that indicated that *Cylindera* (*Ifasina*) *labioaenea* was least sensitive to dessication and flooding when compared with *Calomera angulata* and *Myriochila* (*Monelica*) *fastidiosa*.

Our findings reveal soil preferences of tiger beetles and soil requirements of different species. The findings are important in predicting the occurrence of tiger beetle species in different locations and providing information for the proper management and conservation of soil for the survival of this insect group.

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