# Ground beetle (Coleoptera, Carabidae) assemblages along an urbanisation gradient near Sorø, Zealand, Denmark

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Forekomsten af løbebiller er blevet undersøgt langs en urbaniseringsgradient: skov – træbevokset forstadsareal – park i og nær Sorø, (SZ) fra april til oktober 2004. Fangsten omfattede 2.640 fældeuger (120 fælder × 22 uger) og resulterede i 10.314 voksne biller af 43 arter. Den mest artsrige habitat var parken med 4.389 individer af 37 arter, fulgt af skovhabitaten hvor den samme fangstindsats resulterede i 4.255 individer af 25 arter. De træbevoksede forstadsareal gav den ringeste fangst: 1.670 individer af 24 arter. Cirka 80% af arterne, der var til stede på skovarealet, fandtes også på de urbaniserede arealer. Parkarealet havde den højeste andel af arter, der kun blev fundet dér og ikke på nogen af de to andre arealtyper: 12 arter, svarende til 34%.

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## Introduction

A significant, and increasing amount of terrestrial area is under strong human influence world-wide. In the 20$^{th}$ century, urbanisation became the fastest and most prominent population redistribution trend in the world. Urban areas typically have high human density, energy concentration, pollution, and only remnants of the original habitat (McIntyre et al. 2001). Europe has supported large human populations for centuries, and the original vegetation has been modified in many different ways. Densely populated countries such as Denmark have hardly any "natural" area left. To sensibly manage the remaining biodiversity calls for knowledge of ecosystem responses to the influence of urbanisation (McDonnell & Pickett 1990). Biodiversity is an important indicator of the functional state of ecosystems (Naeem et al. 1994) and contributes to the well-being of city dwellers. Arthropods can be important in both of these functions. Relatively little is known about arthropod responses to urbanisation (Bolger et al. 2000; McIntyre et al. 2001), even though urbanisation is regarded as one of the leading causes of decline in arthropod diversity (Pyle et al. 1981). The effects of urbanisation on nature can be assessed by studying ecosystem structure and function along urban-rural gradients (McDonnell & Pickett 1990).

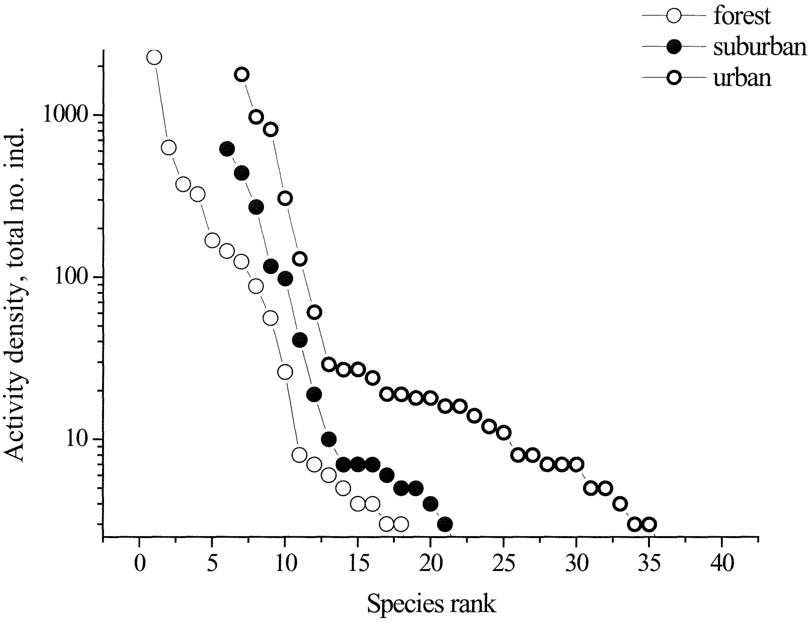


Figure 1. Rank abundance plots of the ground beetle assemblages captured in pitfall traps in the three habitats (forest, suburban, urban) near Sorø, S Zealand, Denmark, during May-October 2004.

This is the aim of Globenet, an international research project conducting comparable studies in different countries to assess the influence of urbanisation on biodiversity (Niemelä et al. 2000). This project applies the urban-rural gradient approach using a common methodology (pitfall trapping) and evaluating the responses of a common invertebrate taxon (ground beetles, Carabidae) to urbanisation. Ground beetles were selected since they are sufficiently varied both taxonomically and ecologically, abundant and sensitive to human disturbances (Lövei & Sunderland 1996).

To date, studies have been published from Finland (Alaruikka et al., 2002; Venn et al., 2003), Canada (Niemelä et al. 2002), Bulgaria (Niemelä et al. 2002), Japan (Ishitani et al., 2003), Belgium (Gaublomme et al., 2005), and Hungary (Magura et al., 2004, 2005). In this paper, we present the first results of Danglobe, the Danish component of this international project.

## Material and methods

Our study area was in and around the town of Sorø, a regional centre in South Zealand, about 80 km west of Copenhagen. The urban, suburban and rural sampling areas were located in a once-continuous beech forest surrounding the city.

The *urban area* was in the park of the Sorø Akademi. This park has old forest patches, individual trees, tall exotic trees, alternating with bushes and extensive mown grass areas. There are only gravel paths, and the mown grass and cut branches are returned to the understory. There are numerous visitors and a boarding school in the park, and the built-up area is about 40%. On one side, Sorø Lake borders the park, and the city centre is on the other side.

The *suburban area* was near the old cemetery, northeast of the town centre. Bordered on one side by an overgrown, old ditch, a dirt road and a wet forest area under intensive forestry management, this area started ca. 1 km from the edge of the park, and extended to the forested area beyond the town. The built-up surface was approximately 20 %, and the understory indicated nitrogen-rich soil (plenty of nettle, *Urtica dioica*). In places, the undergrowth was a tangle of different weeds, a thick carpet of beech saplings, or thick litter layer. The dominant trees were beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*).

The *forest area* was ca. 3 km west from the town centre. A large, near-continuous forest, extending westwards, was bordered by the lake and the outskirts of the town, and by road no. 157 running south. Four different forest blocks were selected that all were dominated by beech. Smaller patches of pine (*Pinus sylvestris*) and other deciduous trees were also present, but only near the edges of forest roads. The forest blocks were under forestry management, but the understory was not thinned, and the trimmed smaller branches were left to rot on the ground. Distance between the sampling areas (urban, suburban, rural) was at least 1 km. The two furthest study areas were approximately 6 km away from each other.

Four sites, at least 50 m from each other, were selected within each habitat. Carabid beetles were collected at each of the 4 sites of the 3 habitat types using pitfall traps. Ten traps were placed at least 10 m apart at each site, giving 120 traps along the urban-rural gradient (3 habitats, 4 sites/habitat, 10 traps/site). Traps consisted of 70 mm diameter plastic cups, sunk into the ground with their rim level with the soil surface; each trap contained about 200 ml of 70% ethylene glycol as a killing-preserving solution. The traps were protected by a 20 cm x 20 cm galvanised iron cover mounted on pegs, with ca. 5 cm gap between the soil surface and the cover. This kept litter and rain out, prevented by-catch of small mammals and herps, and protected the catch from disturbance by small mammals and birds. Traps were checked fortnightly between the end of April and mid-October, 2004. The total trapping effort was 2640 trap-weeks (120 traps × 22 weeks); only very few (<10) catches were lost.

Beetles captured were removed from the trap, put into vials with 70% alcohol, and kept at 4° C until sorting and identification in the laboratory. For identification, keys by Lindroth (1985, 1986) and Hurka (1996) were used, as well as a reference collection kept by GLL at the Flakkebjerg Research Centre. Taxonomy follows Hansen (1996), with changes suggested by Pedersen et al. (2004). For analyses, we pooled samples from the whole season.

## Results

The total catch was 10 314 adult beetles, belonging to 43 species (table 1). The most species-rich habitat was the park, with 4389 individuals of 37 species, followed by the forest habitat, where the same trapping effort resulted in 4255 beetles of 25 species (table 1). The suburban area had the fewest beetles (1670 individuals) and species (24 species, see table 1). About one-third of the species occurred in all three habitats (16 species, 35 %). A further 18 species (39%) were restricted to a single habitat, and 11 species (24%) were captured in two habitats.

The number of unique species was highest at the urban site (12 species, 34% of the species captured in that habitat), and included *Patrobus atrorufus, Calathus rotundicollis, Agonum albipes, Agonum muelleri, Bembidion tetracolum, Agonum piceum, Bembidion biguttatum, Clivina fossor, Elaphrus cupreus, Badister sodalis, Harpalus rufipes,* and *Leistus ferrugineus* (table 2 and 3). The forest site contained 4 unique species (19% of the fauna): *Carabus violaceus, Carabus convexus, Pterostichus lepidus,* and *Stomis pumicatus.*

The highest number of species (see table 2) was shared by the urban and suburban habitats, including 6 species: *Agonum duftschmidi, Anchomenus dorsalis, Pterostichus nigrita,*

Table 1. The list of ground beetle species captured in pitfall traps along the urbanisation gradient near Sorø, S Zealand, Denmark, during May-October 2004. Numbers are seasonal totals.

| Species | Urban | Suburban | Forest | Total |
|---|---|---|---|---|
| *Abax parallelepipedus* (Piller & Mitterpacher, 1783) | 0 | 619 | 2267 | **2886** |
| *Pterostichus melanarius* (Illiger, 1783) | 1780 | 98 | 631 | **2509** |
| *Nebria brevicollis* (F., 1792) | 818 | 117 | 169 | **1104** |
| *Platynus assimilis* (Paykull, 1790) | 975 | 41 | 1 | **1017** |
| *Carabus coriaceus* L., 1758 | 8 | 440 | 375 | **823** |
| *Carabus nemoralis* Müller, 1764 | 307 | 271 | 145 | **723** |
| *Carabus hortensis* L., 1758 | 1 | 19 | 325 | **345** |
| *Pterostichus niger* (Schaller, 1783) | 29 | 10 | 125 | **164** |
| *Patrobus atrorufus* (Ström, 1768) | 130 | 0 | 0 | **130** |
| *Carabus violaceus* L., 1758 | 0 | 0 | 88 | **88** |
| *Trechus secalis* (Paykull, 1790) | 61 | 0 | 0 | **61** |
| *Calathus rotundicollis* Dejean, 1828 | 4 | 1 | 56 | **61** |
| *Leistus rufomarginatus* Duftschimdt, 1812 | 11 | 7 | 26 | **44** |
| *Agonum duftschmidi* Schmidt, 1994 | 27 | 5 | 0 | **32** |
| *Pterostichus oblongopunctatus* F., 1792 | 19 | 7 | 6 | **32** |
| *Agonum albipes* F., 1796 | 27 | 0 | 0 | **27** |
| *Badister bullatus* (Schrank 1798) | 16 | 7 | 3 | **26** |
| *Agonum muelleri* Herbst, 1784 | 24 | 0 | 0 | **24** |
| *Anchomenus dorsalis* (Pontopiddan, 1763) | 18 | 6 | 0 | **24** |
| *Pterostichus nigrita* Paykull, 1790 | 19 | 1 | 0 | **20** |
| *Pterostichus strenuus* Panzer, 1797 | 12 | 4 | 4 | **20** |
| *Bembidion tetracolum* Say,1823 | 18 | 0 | 0 | **18** |
| *Trechus quadristriatus* Schrank, 1781 | 16 | 0 | 1 | **17** |
| *Pterostichus vernalis* Panzer, 1796 | 14 | 0 | 1 | **15** |
| *Notiophilus biguttatus* F., 1779 | 7 | 3 | 4 | **14** |
| *Notiophilus rufipes* Curtis, 1819 | 7 | 5 | 1 | **13** |
| *Harpalus latus* L., 1758 | 5 | 1 | 7 | **13** |
| *Synuchus vivalis* Illiger, 1790 | 1 | 1 | 9 | **11** |
| *Agonum piceum* (L., 1758) | 8 | 0 | 0 | **8** |
| *Cychrus caraboides* L., 1758 | 0 | 2 | 5 | **7** |
| *Bembidion biguttatum* F., 1779 | 12 | 0 | 0 | **17** |
| *Loricera pilicornis* F., 1775 | 3 | 2 | 0 | **5** |
| *Clivina fossor* L., 1758 | 3 | 0 | 0 | **3** |
| *Carabus granulatus* L., 1758 | 2 | 1 | 0 | **3** |
| *Carabus convexus* F., 1775 | 0 | 0 | 3 | **3** |
| *Elaphrus cupreus* Duftschmid, 1812 | 2 | 0 | 0 | **2** |
| *Leistus terminatus* Hellwig in Panzer, 1793 | 1 | 0 | 1 | **2** |
| *Harpalus affinis* Schrank, 1781 | 1 | 1 | 0 | **2** |
| *Badister sodalis* Duftschmid, 1812 | 1 | 1 | 0 | **2** |
| *Harpalus rufipes* Degeer, 1774 | 1 | 0 | 0 | **1** |
| *Leistus ferrugineus* L., 1758 | 1 | 0 | 0 | **1** |
| *Pterostichus lepidus* Leske, 1785 | 0 | 0 | 1 | **1** |
| *Stomis pumicatus* Panzer, 1796 | 0 | 0 | 1 | **1** |
| **Total no. of individuals captured** | **4389** | **1670** | **4255** | **10314** |
| **No. of species** | 37 | 24 | 25 | 43 |
| **No. of species unique to habitat** | 12 | 0 | 4 | |
| **Berger-Parker dominance index** | 0.4 | 0.37 | 0.53 | 0.28 |

Table 2. The number of species shared among the different habitats along the urbanisation gradient near Sorø, S Zealand, Denmark, during May-October 2004.

| *Urbanisation gradient stages & their combinations* | *No. of species shared* |
|---|---|
| Urban-suburban-forest | 16 |
| Urban-suburban | 6 |
| Urban-forest | 3 |
| Urban only | 12 |
| Suburban-forest | 2 |
| Forest only | 4 |
| Total | 43 |

*Loricera pilicornis, Carabus granulatus,* and *Harpalus affinis.* Shared species between the urban and forest site were *Trechus quadristriatus, Pterostichus vernalis and Leistus terminatus.* Only two species were shared between the suburban and forest areas: *Abax parallelepipedus,* and *Cychrus caraboides.*

The common species were, in the order of decreasing abundance: *Pterostichus melanarius, Nebria brevicollis, Platynus assimilis, Carabus coriaceus, Carabus nemoralis, Carabus hortensis, Pterostichus niger, C. rotundicollis, Leistus rufomarginatus, Pterostichus oblongopunctatus, Badister bullatus, Pterostichus strenuus, Notiophilus biguttatus, Notiophilus rufipes, Harpalus latus,* and *Synuchus vivalis.* The species captured in all three habitats made up 42% of the fauna of the urban site, 64% of the suburban site, and 61% of the forest site.

The rank-abundance plots show (figure 1 and table 3) that four species were dominant (relative abundance >10%) when considering the total capture list (*A. parallelepipedus, P. melanarius, N. brevicollis, P. assimilis*). At the urban site, *P. melanarius* was dominant, but there was no dominant species at the suburban site. *A. parallelepipedus* was also dominant at the forest site. Two species, *C. coriaceus,* and *C. nemoralis* were eudominant species overall (relative abundance 5-10%). At the urban site, *P. assimilis* and *N. brevicollis* were eudominant. *A. parallelepipedus* was eudominant only at the suburban site, while *P. melanarius* was eudominant only at the forest site.

Table 3. List of species according to dominance categories captured in pitfall traps along the urbanisation gradient near Sorø, S Zealand, Denmark, during May-October 2004. In brackets are the numbers of individuals captured in that habitat.

| | **Dominant** (10%>x) | **Eudominant** (10%>x>5%) | **Subdominant** (5%>x>1%) |
|---|---|---|---|
| **Total** | *Abax parallelepipedus* (2886) | *Carabus coriaceus* (823) | *Carabus hortensis* (345) |
| | *Pterostichus melanarius* (2509) | *Carabus nemoralis* (723) | *Pterostichus niger* (164) |
| | *Nebria brevicollis* (1104) | | *Patrobus atrorufus* (130) |
| | *Agonum assimile* (1017) | | |
| **Urban** | *Pterostichus melanarius* (1780) | *Platynus assimilis* (975) | *Carabus nemoralis* (307) |
| | | *Nebria brevicollis* (818) | *Patrobus atrorufus* (130) |
| **Suburban** | no species | *Abax ater* (619) | *Carabus coriaceus* (440) |
| | | | *Carabus nemoralis* (271) |
| | | | *Nebria brevicollis* (117) |
| **Forest** | *Abax parallelepipedus* (2267) | *Pterostichus melanarius* (631) | *Carabus coriaceus* (375) |
| | | | *Carabus hortensis* (325) |
| | | | *Nebria brevicollis* (169) |
| | | | *Carabus nemoralis* (145) |

*C. hortensis, P. niger* and *P. atrorufus* were subdominant (relative abundance 1-5%) overall. At the urban site, *C. nemoralis* and *P. atrorufus*, while in the suburban site *C. coriaceus, C. nemoralis* and *N. brevicollis* were subdominant. In the forest site there were five subdominant species: *C. coriaceus, C. hortensis, N. brevicollis, C. nemoralis* and *P. niger.*

The original habitat of the area is forest. Urbanisation under the circumstances in Sorø allowed the presence in other habitats of 21 species (81% of the species that were captured in the forest), but 19% of the fauna was not found in urbanised areas, even if they were very close to the original forest.

## Discussion

Our results suggest that there is a considerable effect of urbanisation on Danish forest carabids. Most of the species we found (40 of the 46 species) are common in Denmark (Bangsholt, 1983). *P. atrorufus,* and *S. vivalis* are moderately frequent.

The number of species captured increased from the urban (park) to the rural (forest) area in Finland (Niemelä et al., 2002; Alaruikka et al., 2002), Japan (Ishitani et al., 2003) and Belgium (Gaublomme et al., 2005). In Denmark, the opposite was found: the urban area (park) had the highest species richness. Similar results were found in Hungary (Magura et al. 2004, 2005). This trend was caused mostly by species attracted to humidity, caused by the vicinity of the Sorø Lake. The nature-friendly management of the park may also have contributed to this: there are numerous patches of wood and grassland, creating habitat heterogeneity. The cut vegetation is not taken away as usual in urban park management (e.g. in Hungary, Magura et al. 2004), but returned to the understory in the forested patches. This may allow natural nutrient cycling, supporting more soil-living arthropods that may provide food for carabid larvae and adults. Further, lack of disturbance may allow carabid larvae to develop. The rural (forest) site was more homogenous than the park and here we found only forest species. There were more forest species here than in other areas; nevertheless, the overall species richness was lower, due to the absence of species that colonised the more modified suburban and park habitats.

We suggest that differences in landscape structure are also important. The landscape in the study area of S Zealand is highly patchy, possibly providing "green corridors" for dispersal. A significant fraction of the fauna can survive in urbanised areas, but about 20% of the species did not occur outside the forest. This underlines that even relatively benign forest and park management can create conditions that are not suitable for forest specialist species. The special conditions in the human-influenced urban areas are also reflected in the high share of unique species in the park. These species did not colonise the suburban or forest habitats, in spite of their relative closeness, as well as some shared botanical features.

Our results indicate that urbanisation may increase the species richness of certain arthropods, while allowing forest species to survive. Nevertheless, urbanisation exerts considerable effects the ground-dwelling target group, Carabidae. Continued work should explore mechanisms that influence the patterns detected and may provide suggestions for habitat management to mitigate the disadvantageous effects of urbanisation on biodiversity.

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