The OPAL Bugs Count Survey: exploring the effects of urbanisation and habitat characteristics using citizen science

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ABSTRACT

Citizen science projects can gather datasets with observation counts and spatiotemporal coverage far in excess of what can easily be achieved using only professional scientists. However, there exists a potential trade-off between the number of participants and the quality of data gathered. The Bugs Count citizen science project had thousands of participants because of its few barriers to taking part, allowing participation by anyone in England with access to any area of outdoor space. It was designed to scope for both the effects of variation in local habitat and urbanisation on broad taxonomic groups of invertebrates, and the responses of six target 'Species Quest' species (*Adalia bipunctata*, *Ocypus olens*, *Aglais urticae*, *Palomena prasina*, *Limax maximus*, and *Bombus hypnorum*) to urbanisation. Participants were asked to search for invertebrates in three areas: 'soft ground surfaces', 'human-made hard surfaces', and 'plants' for fifteen minutes per search. Participants recorded counts of taxa found and a range of environmental information about the survey area. Data samples were weighted according to identification experience and participant age and analysed using canonical correspondence analysis, and tests of observation homogeneity. Species Quest species showed species-specific relationships with urbanisation, but broad taxonomic groups did not show significant relationships with urbanisation. The latter were instead influenced by habitat type and microhabitat availability. The approach used demonstrates that citizen science projects with few barriers to entry can gather viable datasets for scoping broad trends, providing that the projects are carefully designed and analysed to ensure data quality.

Keywords: data quality; environmental education; Open Air Laboratories; public participation in scientific research; scientific literacy; urban-rural gradient

Introduction

The diversity and number of citizen science projects is burgeoning. This is in part because citizen science can offer two important advantages over traditional professional science: (1) more data can be gathered over larger scales of space and time, including from areas otherwise difficult to study (e.g. private property); and (2) the scientific literacy and awareness of participants can be increased, which can potentially help equip communities with the knowledge to better engage with scientific discourse (Cohn 2008, Bonney et al. 2009, Miller-Rushing et al. 2012, Toogood 2013). The Open Air Laboratories (OPAL) citizen science project (OPAL 2012) was launched across England in 2007 and aimed to enhance understanding and enjoyment of the local natural environment, mainly through community participation in environmental science surveys (Davies et al. 2011). The sixth survey, managed by OPAL and the Natural History Museum, was entitled Bugs Count (OPAL 2011) and focused on the effects of urbanisation and habitat characteristics on all higher terrestrial invertebrates, with counts of broad taxonomic groups and six target species that were likely to be affected by urbanisation.

There are many biological citizen science projects and these range widely in their focus and ease of participation (Bonney et al. 2009, Deguines et al. 2012). Some projects emphasise the collection of scientific data; others pay much more attention to engagement aspects, such as awareness raising and enhancing the scientific literacy of participants; and some are designed with equal emphasis on both goals, sometimes known as the win-win model (Cohn 2008, Hobbs and White 2012, Miller-Rushing et al. 2012, Shirk et al. 2012, Toogood 2013). Citizen science can be: (1) Contractual, where citizens ask professional scientists to conduct a scientific investigation; (2) Contributory, where the data are collected by citizens but the research is designed by professional scientists; (3) Collaborative, where citizens also contribute some design, analysis, or dissemination elements to the project; (4)

Co-created, where citizens are actively involved in helping professional scientists through all stages of the project; or (5) Collegial, where projects are developed independent of involvement from professional scientists (e.g. biological recording networks and 'DIY Science') (Miller-Rushing et al. 2012, Shirk et al. 2012). Within dual-aim citizen science projects there is a difficult balance to strike between the competing needs of scientific rigour and the desire to encourage education and awareness. Increasing scientific rigour can make it harder to take part, potentially improving data quality but limiting the number of participants (e.g. Bates et al. 2013), while encouraging education and awareness raising in as many participants as possible by making it easy to take part, can potentially compromise data quality (see discussion in Bonney et al. 2009). The Bugs Count citizen science survey is a contributory project designed to produce scientifically useful results *and* be easy to do (e.g. low time commitments, limited identification skills, low cost, etc.) so that almost anyone of any age and commitment level can participate.

The Bugs Count project focuses on identifying assemblages of higher invertebrates to a relatively low taxonomic resolution, together with six individual species that could be identified easily from photographs. This allowed species-specific responses to urbanisation to be compared with the response of broader invertebrate assemblages. There were several reasons why invertebrates were chosen for this survey. Invertebrates have been termed 'the little things that run the world' (Wilson 1987) and are key components of any ecosystem, occupying a spectrum of trophic levels and niches (McIntyre et al. 2001, Prather et al. 2013). Following the framework of the Millennium Ecosystem Assessment (2005), invertebrates influence the following ecosystem services (e.g. Hunter and Hunter 2008, Prather et al. 2013): (1) diverse supporting services (e.g. soil formation, nutrient cycling, and pollination); (2) limited provisioning services (e.g. honey and wax production, and genetic resources); (3) diverse regulating services (e.g. altering soil hydrology, pest control, and disease regulation);

and (4) some cultural services (e.g. education, enjoyment), especially in urban areas, where a large proportion of wildlife encounters occur. Invertebrates can also influence a range of ecosystem disservices, including: damage to timber, damage to crops and ornamental plants, stinging and biting, causing allergies, disease spread, fear, and discouraging enjoyment/preservation of green spaces (e.g. Lyytimaki and Sipila 2009). Despite this importance, many members of the community have little awareness of invertebrates, or the important role they play, and invertebrates are underrepresented in scientific studies of ecosystem services (Prather et al. 2013, Shwartz et al. 2014). This is perhaps due to the low number of tangible provisioning services provided by invertebrates, and is particularly true in urbanised areas, where relatively few natural products are created (but see e.g. Grewal and Grewal 2012, Taylor and Taylor Lovell 2012).

A wide variety of factors can potentially influence urban invertebrate assemblages relative to surrounding rural areas, including increased air and soil pollution of some pollutants, soil nutrient enrichment and compaction, number of exotic plants, light pollution, irrigation, impervious land cover, CO_2 levels, growing season (urban heat island effect), precipitation; and reduced predation pressure, wind speeds, and permeable land cover (Shochat et al. 2006, Grimm et al. 2008, Pickett et al. 2011). Such a diversity of potentially interacting effects makes the effects of urbanisation on invertebrates difficult to predict. Urbanisation is known to generally reduce the species diversity of invertebrates (McKinney 2008), but patterns can differ due to the geography and historical development of each urban area (Sadler et al. 2006). Knowledge and understanding of the effects of urbanisation on all groups of higher invertebrates is far from complete. There is a small but increasing body of knowledge for some groups e.g. butterflies (e.g. Di Mauro et al. 2007, Bergerot et al. 2010, Deguines et al. 2012), beetles (e.g. Niemelä and Kotze 2009), bees (e.g. Bates et al. 2011, Deguines et al. 2012, Verboven et al. 2014), ants (e.g. Buczkowski and Richmond 2012);

some very limited knowledge for other groups, e.g. moths (e.g. Deguines et al. 2012, Bates et al. 2014), snails (e.g. Horsák et al. 2013), and extremely little knowledge for other groups, e.g. millipedes, Orthoptera, earthworms. For the most part, such studies have investigated the effects of urbanisation on one taxonomic group at a time, and there are very few studies of the concomitant effects of urbanisation across diverse invertebrate taxonomic assemblages (but see McIntyre et al. 2001, Deguines et al. 2012).

Such general lack of information about the overall effects of urbanisation on invertebrates may underlie the limited consideration of invertebrates in studies of urban primary production, carbon cycling, trophic dynamics, and metabolic theory (e.g. Imhoff et al. 2004, Faeth et al. 2005, Zhang 2013). Given the pervasive impact of invertebrates in ecosystem functioning, greater knowledge of the effects of urbanisation on invertebrate assemblages can only improve the understanding of urban ecosystems and their ecosystem services.

We aimed to contribute to the understanding of the broad effects of urbanisation and local habitat characteristics on invertebrate assemblages using easy to take part in citizen science. Specifically, we had the following objectives:

- To assess how well the OPAL bugs count survey gathered useful scientific data, given that the controls on the way the data were collected were as few as possible;
- To assess the effects of urbanisation and habitat characteristics on invertebrate and feeding/functional group assemblages at a broad taxonomic level;
- To assess the effects of urbanisation on the presence of six species of invertebrates to look for species specific effects.

Methods

The OPAL and Natural History Museum Bugs Count survey

The survey was launched in June 2011 and widely publicised through television, radio, print and on-line popular media. Thirty thousand survey packs were distributed across England to a wide range of individuals and groups including schools, wildlife charities, natural history groups and local government. In addition, all survey resources were available to freely download from OPAL (2011) and a further twelve thousand surveys were distributed in this way. Many participants were supported in their survey participation by OPAL staff, or volunteers trained by OPAL staff, but many people participated in the survey without direct staff contact. Data could be uploaded to the OPAL database via the web page, or returned via a freepost address. In the first year, data from over five thousand surveys were completed and added to the national database, but it is thought that more than twenty thousand people took part. The analyses reported here use Bugs Count data collected from England (although there was wider UK and overseas participation) from 2011-2012.

The survey pack included three main components that provided the information necessary to complete the survey: the Field Notebook, the Pocket ID Guide and the Species Quest information sheet. The Field Notebook contained information on the importance of invertebrates, the process of urbanisation, the range of invertebrate microhabitats in the built environment, all the methodological instructions needed to take part in the survey, and sheets for recording data. The Pocket ID Guide contained photographs and identification tips to aid the identification of the study taxa. It was broadly separated into convenient colour sections for ease and speed of identification, related to number of legs: no legs, 6 legs, 8 legs and lots of legs.

The Species Quest information sheet covers information on the identification of six key study species described below, together with details of where to upload or email digital photographs for identification confirmation. An additional method of recording Species Quest data was added in September 2011 with the launch of Apple ® and Android ™ Apps, which allowed instant submission of photographs of the Species Quest invertebrates. The free apps were downloaded over ten thousand times in the first year.

Method standardisation

The wider habitat (sensu Dennis et al. 2003) of invertebrate includes a diverse range of micro-habitats because utilization varies with the time of day, seasons, weather conditions and life-history stage. In urban environments, micro-habitats can include buildings and human-made hard surfaces (such as walls or pavement) for basking (e.g. butterflies), hunting (e.g. jumping spiders), nesting (e.g. Red Mason Bees, *Osmia bicornis* (Linnaeus, 1758)), and overwintering (e.g. mosquitoes). To prevent creating participation barriers associated with access to semi-natural green space, all potential habitats were included in the Bugs Count survey. Clearly, the abundance and diversity of invertebrates present on a wall and species rich grassland, for example, will differ considerably, and to include data from the full range of potential habitats would severely stretch the assumptions of most statistical methods. Therefore, three distinct survey 'challenges' were defined, with separate explanatory environmental variables collected for each. Challenge 1 was a search for invertebrates living on soft ground surfaces such as soil, short grass (shorter than the pocket identification guide, length of <115 mm), and amongst leaf litter. Challenge 2 was a search for invertebrates on human-made hard surfaces such as paving, fences, and the outside of buildings. Challenge 3 was a search for invertebrates on plants such as long grass (>115 mm), flowers, shrubs, and trees.

Participants were allowed to survey as large an area as they liked, but asked to spend exactly 15 minutes doing the survey for each of the three challenges. Invertebrates found had to be identified *during* the fifteen minutes. Sample effort was therefore standardised as far as practicable by time, rather than area. This would lower barriers to participation for those people with access to only small potential survey areas. Participants were asked to complete questions on environmental explanatory variables outside of the fifteen minutes. In order to gather information on search effort, participants were asked to record how many people were in their survey team. Relatively few participants answered this question, and when they did, it was not clear whether all members of the team were actively searching for invertebrates, whether some were searching and others recording the data, or whether the majority were watching/learning from a group leader (e.g. teacher) who was doing most of the active searching. Therefore the group size variable could not be used in further analyses.

Study taxa – Challenges 1-3

The Bugs Count survey was designed to have few barriers to participation, so did not assume that participants had any existing invertebrate identification skills. Participants were asked to identify invertebrates to one of sixteen broad taxonomic groups which were difficult to confuse (snails, earthworms, crickets/grasshoppers, and so on) with the help of the Pocket ID Guide. The sixteen taxonomic groups were for the most-part aligned quite closely with various feeding groups. For example, bees and wasps are difficult to tell apart without prior experience, but both will visit flowers to feed on nectar and therefore play a role in providing a pollination ecosystem service. Table 1 details the taxonomic groups used and the broad feeding/functional groups assigned for later analyses. Taxonomic groups that included several feeding/functional groups, such as the beetles, were not assigned to any particular group and therefore not included in ecosystem service analyses.

Explanatory environmental variables – Challenges 1-3

Full details of the questions asked to generate environmental explanatory variables can be found at OPAL (2011). Questions were designed to be as short and unambiguous as possible. Some samples were associated with explanatory variable categories with a small number of observations. Such categories were either amalgamated into larger categories or removed from further analyses (together with the associated samples). Data from June 2011 to May 2012 were analysed. December 2011, January 2012, and February 2012 had a small number of observations so were removed from subsequent analyses. June - August 2011, September - November 2011, and March - May 2012 were classed as the categorical dummy variables ‘summer’, ‘autumn’, and ‘spring’ respectively. There were few observations from streets/estates, waste grounds, and ‘other’ habitats, so these data were removed from subsequent analyses, leaving four study habitats: woodland, gardens, park, and grassland.

Table 2 shows the explanatory variables used in analyses. Additional explanatory variables were created using the postcodes provided by participants, namely latitude and longitude (in decimal degrees), Index of Multiple Deprivation (IMD) score (ranking of deprivation of seven types e.g. employment, health and education), and urbanisation (urban/rural indicators URI). The IMD and URI data were downloaded from GeoConvert (2012). Postcodes were matched to Lower Super Output Areas to get IMD data from the Indices of Deprivation 2007. URI codes were used to associate postcodes with ‘urbanized’ (urban and suburban areas of towns and cities, URI codes 1, 2, 5, and 6) and ‘rural’ (countryside, hamlets and villages, URI codes 3, 4, 7, and 8) areas.

Challenge 1-3 data quality control

Misidentification of study taxa is a potential problem associated with ecological citizen science data, but careful data validation and error checking can help reduce the amount of erroneous data (e.g. Bonney et al. 2009, Bone et al. 2012, Bonter and Cooper 2012, Deguines et al. 2012). The Bugs Count survey asked participants ‘who are you doing the activities with today?’ with participants able to answer: (1) primary school, (2) secondary school, (3) other youth group, (4) college/university, (5) adult volunteer group, (6) family or friends, or (7) on your own. The answers were used to assume that most of those who answered: 1 = children <12 years old, 2 and 3 = 12-17 years old, and 4-7 = >17 years old. It also asked participants ‘have you identified invertebrates before’ with participants able to answer yes or no.

In separate unpublished trials (ID Accuracy Trials n = 418), people of various ages and experience level were asked to identify sample trays of ten diverse invertebrates, of varying difficulty, that were likely to be found in Bugs Count surveys. To reflect the limited time available in the Bugs Count survey, time was limited to 5 minutes in the ID Accuracy Trials and participants were asked to identify the samples to the same broad taxonomic level used in the Bugs Count survey using the Pocket ID Guide. ID Accuracy Trial participants were asked which of the three age categories (<12, 12-17, or >17) they belonged to, and whether they had previous experience of identifying invertebrates. Overall identification accuracy in the ID Accuracy Trial was 71%, but this varied depending on age and experience of the participant, with >17 year olds the most accurate, 12-17 year olds less accurate (13.4% less accurate than adults), and <12 year olds still less accurate (18.9% less accurate than adults). Those with previous identification experience were more accurate, and those with no invertebrate identification experience were less accurate (15% less accurate than those with experience). This information was used to create the age and experience weightings (Table 2) used in the Bugs Count data analyses.

In addition to sample weighting according to likely identification accuracy, samples were cleaned in a data rationalisation process, where likely erroneous or duplicate entries were removed. It was clear from the answers to questions on habitat and reported abundances of certain taxa that a small number of participants were searching for invertebrates in areas outside the microhabitats described for an individual challenge (for example, samples for Challenge 2 [hard surfaces] that reported the survey area to be all soft surfaces, or samples for Challenge 3 [plants] that reported large counts of earthworms). Such samples were removed from analyses. Some samples included counts far in excess of other counts of the same taxa (e.g. >100 beetles, >80 crickets/grasshoppers, >280 spider webs) and were considered likely errors relative to the other data and in the experiences of the authors, and so were removed (see also: Bonney et al. 2009, Bonter and Cooper 2012). Counts of true bugs for Challenge 3 (plants) were problematic because some participants were including aphids while some participants were not, so true bug counts were excluded from this analysis. Counts of ants were also problematic, being strongly bimodal depending on whether a nest was/was not discovered in the survey area. In addition, their large abundances can swamp abundance patterns in other taxa (e.g. McIntyre et al. 2001). Counts of ants were excluded from analyses of Challenge 1 (soft) and Challenge 3 (plants) data.

Challenge 1-3 data analyses

Data were analysed using ordination of the three separate datasets in Canoco for Windows version 4.51 (ter Braak and Šmilauer 1998). Ordination is a method of summarising multivariate data, so that multidimensional information can be reduced to two dimensional information that can be more easily visualised and interpreted. Counts of individual taxa were used as the ‘species’ response data. Total abundance, richness of taxa, total pollinators, herbivores, and detritivores were used as supplementary variables (i.e. passive variables, with patterns shown on ordination diagrams, but which do not affect the ordination statistics). Latitude, longitude, season, and weather were used as covariables (i.e. included within the ordination statistics, but not the focus of the investigation, so not shown on ordination diagrams). Site, IMD score, soft surfaces, total microhabitats, and individual microhabitats were used as explanatory environmental variables. Age and experience weights were multiplied to create combined sample weights for use in the analyses (Table 2). The gradient lengths from preliminary indirect ordinations using partial detrended correspondence analyses (pDCAs) were all long (largest >4, all >3) so partial canonical correspondence analysis (pCCAs) was the preferred method (Lepš and Šmilauer 2003). Scaling was by interspecies distance with Hill's scaling. Environmental variables (*P*<0.05) were selected using manual forward selection using Monte Carlo simulations under the full model (9999 unrestricted permutations and a random seed).

Early attempts at modelling the data tended to be unstable, included results that were difficult to biologically interpret, and explained very small amounts of variation in the data. In unstable models the inclusion or removal of one environmental variable changed the relationship between the taxa and other environmental variables in the model (i.e. patterns shown in the model were unreliable). Excluding data collected from the category 'school and university grounds' (dominated by schools data) led to more stable, biologically interpretable models, which better explained the variation in the data.

The Species Quest data

While participating in the Bugs Count challenges, or separate from these challenges, people were asked to report sightings of six species of invertebrate: Two-spot Ladybird (*Adalia bipunctata* (Linnaeus, 1758)), Devil's Coach Horse (*Ocypus olens* (Müller, O.F., 1764)), Small Tortoiseshell (*Aglais urticae* (Linnaeus, 1758)), Green Shieldbug (*Palomena prasina* (Linnaeus, 1761)), Leopard Slug (*Limax maximus* Linnaeus, 1758), and Tree Bumblebee (*Bombus hypnorum* (Linnaeus, 1758)). Given the relative difficulty of identifying these species for those with little identification experience, only records with attached photographs (e.g. Deguines et al. 2012) showing correctly identified individuals were used in further analyses. For the most part, these records were individual records with a date and location but no other associated environmental information, rather than being observations associated with a Bugs Count survey.

To test whether each species showed evidence of favouring urbanized (urban and suburban areas) or rural sites, records were classified as urbanized or rural (countryside or villages less than 1x1 km) using Google Earth by AJB. Multiple records from the same site were removed to leave one record for each site, so that records indicated presence at that site. A test of homogeneity of observations would expect to find an equal number of observations in urbanized and rural areas if the target species showed no preference for urbanized and rural areas, and if sampling effort was equal between urbanized and rural areas. However, there was clearly more sampling effort in urbanized areas, where 344 observations were made, compared to 189 observations in rural areas (this was fairly typical of OPAL projects overall as a consequence of the distribution of OPAL staff, and population concentration in urban areas). Therefore, for each of the six target species, the summed ratio of urbanized to rural observations in the remaining five species was used as a proxy for sampling effort to predict the expected ratio in the target species. Differences between the observed and expected frequencies of urbanized to rural sites were tested for significance using χ^2 two-category goodness of fit tests.

Results

Comparisons between the three challenges

Following data rationalisation, each of the three challenges had similar numbers of responses from each of the four analysed site types, with most surveys carried out in gardens (just over 50%), then woodlands (just over 20%), parks (around 15%), and grasslands (around 10%). The richness, total abundance and abundance of pollinators, herbivores, detritivores, and predators (used as supplementary variables in the below analyses) had large ranges and skew (Table 3). Nonetheless, within Challenge 1 (soft surfaces n = 707) detritivores were most abundant. Within Challenge 2 (hard surfaces n = 384) there were also large counts of detritivores, but the largest counts were of predators. Within Challenge 3 (plants n = 504), counts of predators and pollinators were highest, but counts of detritivores were generally much lower than the other two challenges.

Challenge 1: soft surfaces

Significant taxa-environment relationships were identified using partial canonical correspondence analysis for Challenge 1, although relatively little of the variance in taxa (species) counts was explained (Table 4, Fig. 1). The four study habitats were strongly separated, with gardens associated with more detritivores (particularly woodlice), parks, and grasslands associated with more pollinators, and woodlands associated with more herbivores and predators. Parks, grasslands, and woodlands were associated with larger taxa richness than gardens. Soft surfaces, deprivation score, large objects, deadwood and leaf litter were all selected for inclusion in the ordination. Urbanisation was not selected for inclusion in the ordination.

Challenge 2: human-made hard surfaces

Significant taxa-environment relationships were also identified using partial canonical correspondence analysis for Challenge 2, and again relatively little of the variance in taxa (species) counts was explained (Table 4, Fig. 2). The four study habitats were again strongly separated, with gardens associated with the largest total abundance and abundance of predators, grasslands associated with the abundance of detritivores, and woodlands associated with the highest counts of beetles. Soft surfaces, play equipment, and wooden decking/walkways were all selected for inclusion in the ordination. Urbanisation was again not selected for inclusion in the ordination.

Challenge 3: plants

Despite careful rationalisation of the challenge 3 data, no reasonable ordination could be achieved that was stable and biologically interpretable, despite test models being significant.

Species Quest data

The number of records of Two-spot Ladybird showed no evidence of this species favouring either urbanized or rural areas (Table 5). Devil's Coach Horse and Leopard Slug showed some evidence of an association with rural areas, whereas Green Shieldbug showed some evidence of an association with urbanized areas. Small Tortoiseshell showed a strong association with rural areas, whereas Tree Bumblebee showed a strong association with urbanized areas.

Discussion

Data quality

The data characteristically had large ranges and skew, which was unsurprising given the wide ranging geographical spread, weather conditions, and seasons over which surveys were implemented. In addition, participants ranged widely in both search skill and enthusiasm levels. This variation was all to some extent incorporated in the analyses; however, given the complexity of the working landscape and the wide spatio-temporal variation across this study, one might assume that finding statistically significant and biologically interpretable patterns in the data would be difficult, if not impossible. Unsurprisingly, relatively small amounts of the variation in the studied assemblages were explained, but crucially, patterns were statistically significant and biologically meaningful. Given the nature of the data this finding was encouraging.

Nevertheless, there were inevitably some systematic errors and erroneous samples in the dataset. For example, the counts of predators in the datasets are perhaps unrealistically high, possibly because spider webs and fast moving centipedes are particularly obvious and thus easier to detect, or because it was possible for participants to double count both a spider web and a spider as individual predators. Samples more likely to be erroneous because of the age or experience of participants were down-weighted, and obviously inflated counts could be detected and removed from analyses. However, the detection of erroneously low counts is particularly difficult. Such counts could either be genuine due to, for example, limited habitat availability or poor weather conditions, or erroneous, due to a poorly motivated participant or one unwilling to disturb garden vegetation. The inevitability of having some errors in a citizen science dataset is offset by the large sample pool (large n), which creates a favourable signal to noise ratio and thereby reduces the influence of errors in the overall findings (Bonney et al. 2009, Bonter and Cooper 2012). Nonetheless, we consider citizen science projects of the form employed in this study that had very few limits to participation, to perhaps be best suited for scoping broad trends that can then be explored in later, smaller-scale studies (see also discussion in Bonney et al. 2009). In other words, it is perhaps more suitable for hypothesis generation, rather than hypothesis testing.

Effect of local habitat

Correlations between invertebrate assemblages and broad habitat type (woodlands, parks, grasslands and gardens), microhabitat search area (Challenges 1-3) and microhabitat availability were all shown in the data. Different habitats support different invertebrate assemblages, and this holds true along urbanisation gradients (e.g. McIntyre et al. 2001, Angold et al. 2006). Microhabitat availability has also been found to influence invertebrate assemblages in other studies (Smith et al. 2006a, Smith et al. 2006b, Bates et al 2014). This suggests that designing habitats to encourage invertebrate diversity in the built environment (e.g. Hunter and Hunter 2008, Sadler et al. 2011) is likely to have some success. It was interesting that there was evidence to suggest that the presence of some ‘cultural feature’ microhabitats such as decking and play equipment (Beumer and Martens in press), can also directly or indirectly influence invertebrate assemblages.

Effect of urbanisation

A number of other studies have also found weak or no relationships between several invertebrate taxa and urbanisation intensity (e.g. Smith et al. 2006a, Smith et al. 2006b, Sattler et al. 2010). There may well have been more subtle effects of urbanisation in our data, which our analyses lacked the power to detect. However, our results suggest that the effect of urbanisation on higher invertebrate assemblages and invertebrate feeding/functional groups was weaker than both variation in habitat type and the availability of microhabitats. This lack of broad changes in higher invertebrate assemblage with urbanisation is preliminary encouraging news for the provision of *in situ* ecosystem services in towns and cities.

Studies of the cultural services provided by invertebrates remain rare, however, Fuller et al. (2007) and Shwartz et al. (2014) have shown that non-ecologists are usually not consciously aware of invertebrates, or able to perceive their diversity. We believe therefore that providing invertebrate taxa and functional group diversity is not markedly depauperate, most people will appreciate a typical invertebrate assemblage as much as one marked for its conservation value or diversity. In terms of cultural ecosystem services therefore, perhaps with the exception of existence value, the value of invertebrate assemblages in towns and cities compared to those found in the countryside are likely to be reasonably equivalent. This will potentially facilitate the enjoyment of participants in activities such as Bugs Count in habitats of wide-ranging type and habitat quality.

Predicting the effects of altered assemblage on trophic dynamics and functionality is difficult (Faeth et al. 2005, Hooper et al. 2005). Although large differences have been found between urban and rural areas in desert ecosystems due to urban watering (Faeth et al. 2005), in temperate areas, differences might be expected to be more subtle. Due to functional redundancy, whereby several species perform similar functional roles, many ecosystem services can be robust to the effects of species loss (e.g. Memmott et al. 2004, Hooper et al. 2005). Our preliminary finding of little difference between urban and rural higher invertebrate assemblages and functional/feeding groups, suggests that broad invertebrate facilitated ecosystem services might remain intact in temperate towns and cities. However, the loss of a dominant, keystone, or ecological engineer species can sometimes have a disproportional effect on ecosystem functioning and service provision (Hooper et al. 2005). So the effect of urbanisation on the occurrence and abundance of individual species also needs to be considered.

Species Quest trends

The differing number of observations in urbanized and rural locations for the six study species suggests that, as might be expected, responses to urbanisation are species-specific. Five of the six species showed some detectable response to urbanisation, with three species commoner in rural areas, and two species commoner in urbanized areas. However, given the many possibilities for sampling bias associated with the methods, we adopted $P<0.01$ as a more conservative threshold for statistical significance, and only discuss further the trends for Small Tortoiseshell (*Aglais urticae*) and Tree Bumblebee (*Bombus hypnorum*).

Once common and abundant, Small Tortoiseshell has declined in recent years across The Netherlands (Van Dyck et al. 2009) and the UK (Fox et al. 2011), and may well have declined in other highly developed landscapes across its range (all of Europe and most of Asia). Van Dyck et al. (2009) found the decline to be stronger in urban areas, suggesting that this species is negatively associated with urbanisation, supporting our own findings. In Switzerland, Altermatt (2012) found that the first appearance (25% of individuals observed during the flight period per year) of Small Tortoiseshell was nearly 20 days later in (warmer) settlement habitats than (cooler) agricultural habitats. The preferred display and oviposition sites of Small Tortoiseshell are sunlit, containing nettles (larval foodplant and roost), by the edge of a wall or hedge (Baker 1972), and although this combination of microhabitats occurs in urbanized areas, suitable habitats are more likely to be found in rural areas. These findings suggest that the larval, breeding, and overwintering microhabitats of Small Tortoiseshell are likely to be mainly outside urbanized areas, with adults (possibly the second brood particularly) dispersing to urbanized areas randomly during nectar foraging bouts, when they move in a relatively straight line related to the azimuth of the sun (Baker 1968). These factors would explain the negative association with urbanized areas found in the Species Quest data.

In contrast to Small Tortoiseshell, Tree Bumblebee was found to be positively associated with urbanized areas, and this species has increased its range and abundance across England following its arrival in the country in 2001 (Stuart Roberts pers. comm.). The occurrence of this species was also found to be positively associated with urbanized areas by Bates et al. (2011) in Birmingham, England. The species is known to like to nest aerially in old bird boxes and roof cavities, and likes to forage on planted shrubs such as *Cotoneaster* species, which might explain its current apparent preference for urbanized areas.

Implications for citizen science projects

Not all citizen science projects include systems to check data quality (Crall et al. 2010), but as shown in this and other studies, systems to manage citizen science data quality are essential (Cohn 2008, Bonney et al. 2009, Bonter and Cooper 2012, Miller-Rushing et al. 2012). Our study shows that even low barrier to entry citizen science can deliver useful and biologically interpretable results, but this was only achieved in this instance through retrospective data rationalisation and weighting according to age and experience. Other studies (e.g. Bonney et al. 2009; Bonter and Cooper 2012) have used automatic filters to identify potential errors in data entry and to encourage entry of all necessary data. Such approaches should be encouraged when they do not compromise participation, such as on-line automatic unusual data entry warnings, that still allow the entry of unusual data if the participant chooses (e.g. Bonter and Cooper 2012).

Taking part in citizen science projects can alter the behaviour and improve the scientific literacy of participants (Bonney et al. 2009, Miller-Rushing et al. 2012, Toogood 2013), so participation by as many people as possible should be encouraged where this is part of the aim of the citizen science project. Data that are likely to be of poorer quality due to participant age, background, or experience can be weighted accordingly so that confidence can be maintained in the findings without too much data loss. This approach does, however, require the collection of demographic and level of experience data and supporting studies of how these factors affect data quality.

In the Bugs Count study, data from schools were found to be unreliable, but this does not mean that useful citizen science data cannot be collected in schools, or that useful data cannot be collected by children. Around 38% of the data remaining in the analyses after data rationalisation was collected by children. We recommend area-standardized or methodologies based on the completion of a task, for use in schools, rather than time-standardized samples. This is because time-standardisation is likely to be difficult in situations where teachers have to control children who are excited to be outside, while teaching the survey methodology and curriculum.

Large amounts of invertebrate data were removed from the Bugs Count analyses because the associated habitat, demographic, and experience data were missing or incomplete. We found when running Bugs Count surveys that participants were less enthusiastic about recording these explanatory variables than they were about recording the numbers of invertebrates. Methods to stress the importance of supporting data, and enthuse participants to collect it are important in any citizen science project.

Conclusions

This investigation has shown that citizen science with few obstacles to participation, can be used to generate useful scientific findings, even when investigating complicated real working landscapes over wide spatio-temporal sampling windows. However, due to limited investigative design control when using citizen scientists to gather data over large spatial scales, such an approach is perhaps in many cases more suitable as a scoping tool for hypothesis generation rather than hypothesis testing. Low barriers to entry citizen science projects require careful data validation and robust data rationalisation procedures, in order to ensure that as much of the data as possible can be used in scientific analyses. Nonetheless, even when a sample is removed from data analyses, the participant that generated that sample is likely to benefit from participating in the scientific process, so participation for all should be encouraged.

Differences in habitat type and microhabitat availability were shown to influence the diversity, abundance, and potential ecosystem service provision of broad taxonomic groups of invertebrates. Effects of urbanisation were not detected for the same broad taxonomic groups but were detected at the species level. Broad findings from such citizen science with few obstacles to participation can be used to pragmatically inform future research questions and perhaps best focus finite professional scientific resources.

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List of Tables

Table 1
Taxa and their feeding/functional group counted in the Bugs Count survey.

Number of legs	Taxa	Feeding/functional group
0	Snails (Gastropoda)	Herbivores
0	Slugs (Gastropoda)	Herbivores
0	Earthworms (Lumbricina)	Detritivores
6	Beetles (Coleoptera)	-
6	True bugs (Hemiptera)	Herbivores
6	True flies (Diptera)	-
6	Bees and wasps (Hymenoptera)	Pollinators
6	Ants (Formicidae)	Detritivores
6	Butterflies and moths (Lepidoptera)	Herbivores and pollinators
6	Crickets and grasshoppers (Orthoptera)	-
6	Earwigs (Dermaptera)	Detritivores
6	UFI's unidentified flying insects*	-
8	Spiders and harvestmen (Arachnida)	Predators
>8	Woodlice (Oniscidea)	Detritivores
>8	Centipedes (Chilopoda)	Predators
>8	Millipedes (Diplopoda)	Detritivores
Hard to see	Insect larvae	-
na	Spider webs	Predators
na	Other invertebrates (e.g. Odonata, Collembola)	-

* only counted in Challenge 3 - tall plants

Table 2
Explanatory variables used in the data analyses of the three Bugs Count challenges (env. = environmental, IMD = Index of Multiple Deprivation, ID = identification).

Variable	Type	Levels	Used in challenge(s)
Season	categorical dummy, covariable	spring, summer & autumn	all
Weather	ordinal, covariable	raining 1, cloudy no rain 2, partly sunny 3, sunny 4	all
Latitude	continuous, covariable	decimal degrees, 50.18 to 55.75	all
Longitude	continuous, covariable	decimal degrees, -5.32 to 1.66	all
Site	categorical dummy, env. variable	garden, woodland, grassland, park	all
Urbanization	categorical dummy, env. variable	developed 1, rural 2	all
Age weighting	proportion, weight	primary 0.811, secondary 0.866, adult 1	all
Experience weighting	proportion, weight	no ID experience 0.85, some ID experience 1	all
IMD score	continuous, env. variable	0.7 to 80.62	all
Soft surfaces	ordinal, env. variable	none 0, a little 1, about half 2, most 3, all 4	all
Total abundance	continuous, supplementary variable	1 to 274	all
Richness of taxa	continuous, supplementary variable	1 to 17	all
Total pollinators	continuous, supplementary variable	0 to 99	all
Total herbivores	continuous, supplementary variable	0 to 114	all
Total detritivores	continuous, supplementary variable	0 to 181	all
Total predators	continuous, supplementary variable	0 to 138	all
Soil (e.g. flower bed)	categorical binomial, env. variable	0, 1	1
Short grass	categorical binomial, env. variable	0, 1	1
Leaf litter	categorical binomial, env. variable	0, 1	1
Large objects (e.g. plant pots, large stones)	categorical binomial, env. variable	0, 1	1
Dead wood	categorical binomial, env. variable	0, 1	1
Open compost heap	categorical binomial, env. variable	0, 1	1
Total soft	ordinal, env. variable	sum of microhabitats, 0-6	1
Building	categorical binomial, env. variable	0, 1	2
Wall	categorical binomial, env. variable	0, 1	2
Wooden fence	categorical binomial, env. variable	0, 1	2
Paving	categorical binomial, env. variable	0, 1	2
Wooden decking/walkways	categorical binomial, env. variable	0, 1	2
Pavement (tarmac, concrete)	categorical binomial, env. variable	0, 1	2
Plant pots	categorical binomial, env. variable	0, 1	2
Play equipment	categorical binomial, env. variable	0, 1	2
Total hard	ordinal, env. variable	sum of microhabitats, 0-8	2
Long grass	categorical binomial, env. variable	0, 1	3
Flower bed	categorical binomial, env. variable	0, 1	3
Wild flowers	categorical binomial, env. variable	0, 1	3
Hedges	categorical binomial, env. variable	0, 1	3
Shrubs	categorical binomial, env. variable	0, 1	3
Trees	categorical binomial, env. variable	0, 1	3
Climbing plants	categorical binomial, env. variable	0, 1	3
Total plants	ordinal, env. variable	sum of microhabitats, 0-7	3

Table 3
Data spread in the supplementary variables used in the analyses for the three challenges.

Challenge 1	Total abundance	Richness of taxa	Pollinators	Herbivores	Detritivores	Predators
25th percentile	11	4	0	1	1	0
Mean	33.0	6.0	3.4	5.6	11.3	4.3
75th percentile	42	8	5	7	11	5
Maximum	274	15	51	114	181	102
Challenge 2	Total abundance	Richness of taxa	Pollinators	Herbivores	Detritivores	Predators
25th percentile	12	3	0	0	0	1
Mean	41.3	5.8	2.0	3.3	9.8	11.6
75th percentile	55	8	2	3	10	15
Maximum	273	17	33	47	110	138
Challenge 3	Total abundance	Richness of taxa	Pollinators	Herbivores	Detritivores	Predators
25th percentile	11	3	1	0	0	1
Mean	33.8	5.3	7.0	4.5	1.6	7.1
75th percentile	43	7	9	6	1	10
Maximum	266	15	99	49	40	61

Table 4
Eigenvalues, species-environment correlations, cumulative percentage variance in species data explained, and significance of first and all canonical axes in the partial canonical correspondence analysis for Challenges 1 and 2.

Challenge 1	Axis 1	Axis 2
Eigenvalues	0.240	0.040
Species-environment correlations	0.817	0.607
Cumulative % variance of species data	7.3	8.5
Significance of first canonical axis	F-ratio = 54.449	P<0.001
Significance of all canonical axes	F-ratio = 9.729	P<0.001
Challenge 2	**Axis 1**	**Axis 2**
Eigenvalues	0.072	0.029
Species-environment correlations	0.482	0.735
Cumulative % variance of species data	2.7	3.8
Significance of first canonical axis	F-ratio = 10.488	P<0.001
Significance of all canonical axes	F-ratio = 3.626	P<0.001

Table 5
Tests of homogeneity for the number of urbanized and rural records of the six Species Quest study species. Expected numbers are based on the proportion of urbanized and rural records in the remaining five species (spp. = species, prop. = proportion, NS = not significant).

	Observed		Count of other 5 spp.		Prop. of other 5 spp.		Expected				
Species	Urbanized	Rural	Urbanized	Rural	Urbanized	Rural	Urbanized	Rural	Trend	χ^2	Significance
Devil's Coach Horse	20	22	324	167	0.66	0.34	27.7	14.3	+ rural	6.1	P<0.05
Green Shieldbug	70	25	274	164	0.63	0.37	59.4	35.6	+ urbanized	5.2	P<0.05
Leopard Slug	53	44	291	145	0.67	0.33	64.7	32.3	+ rural	6.2	P<0.05
Small Tortoiseshell	18	43	326	146	0.69	0.31	42.1	18.9	+ rural	44.0	P<0.01
Tree Bumblebee	131	28	213	161	0.57	0.43	90.6	68.4	+ urbanized	42.1	P<0.01
Two-spot Ladybird	52	27	292	162	0.64	0.36	50.8	28.2	none	0.1	NS

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Fig. 1. Partial canonical correspondence analysis of the Challenge 1 (soft surfaces) data. Small dots show individual samples. Garden, park, grassland, woodland, soft surfaces, deprivation, large objects, deadwood and leaf litter were significant environmental explanatory variables. Detritivores, total abundance, pollinators, richness, herbivores, and predators are supplementary variables.

Fig. 2. Partial canonical correspondence analysis of the Challenge 2 (hard surfaces) data. Small dots show individual samples. Garden, park, grassland, woodland, soft surfaces, play equipment, and decking were significant environmental explanatory variables. Detritivores, total abundance, pollinators, richness, herbivores and predators are supplementary variables.

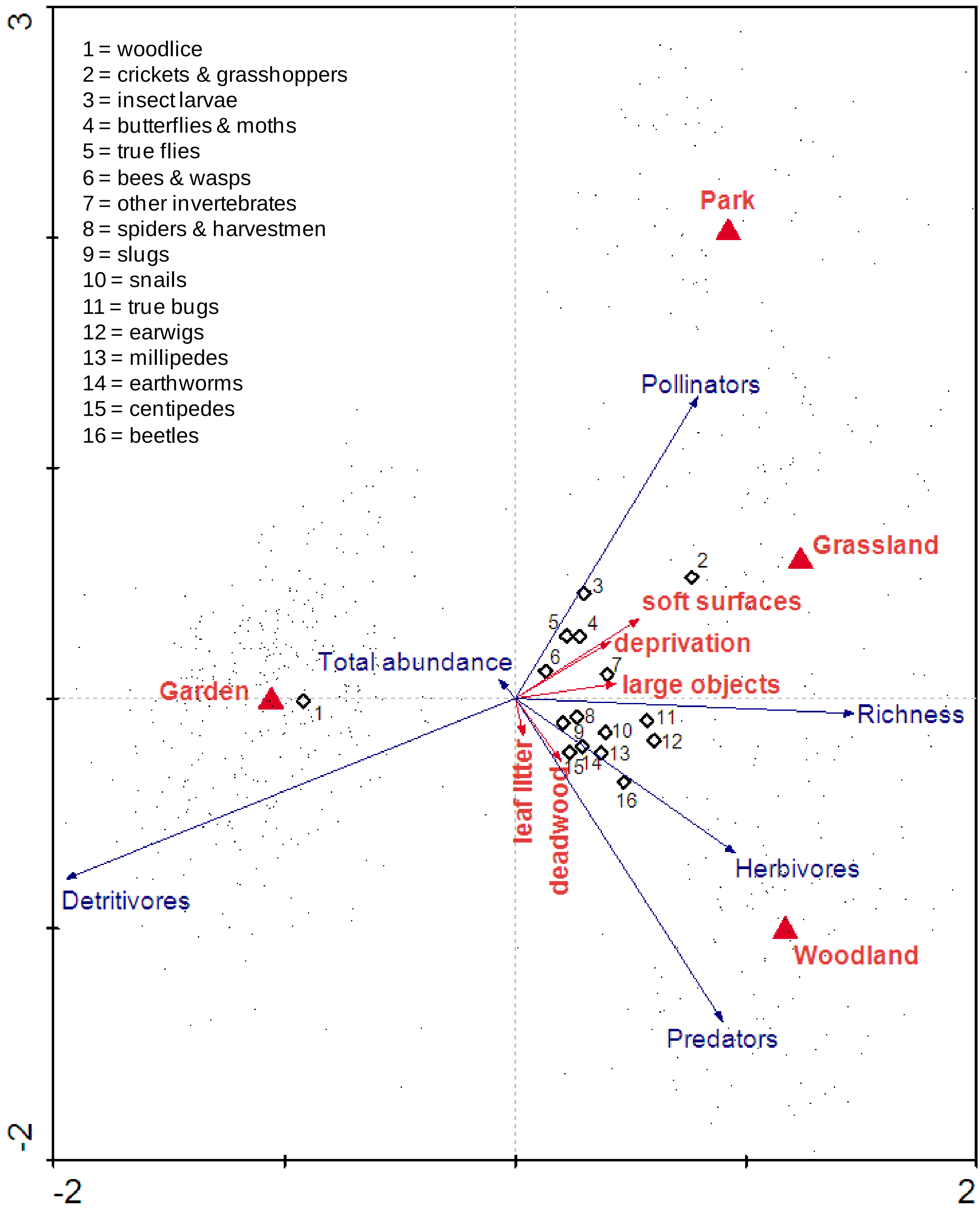
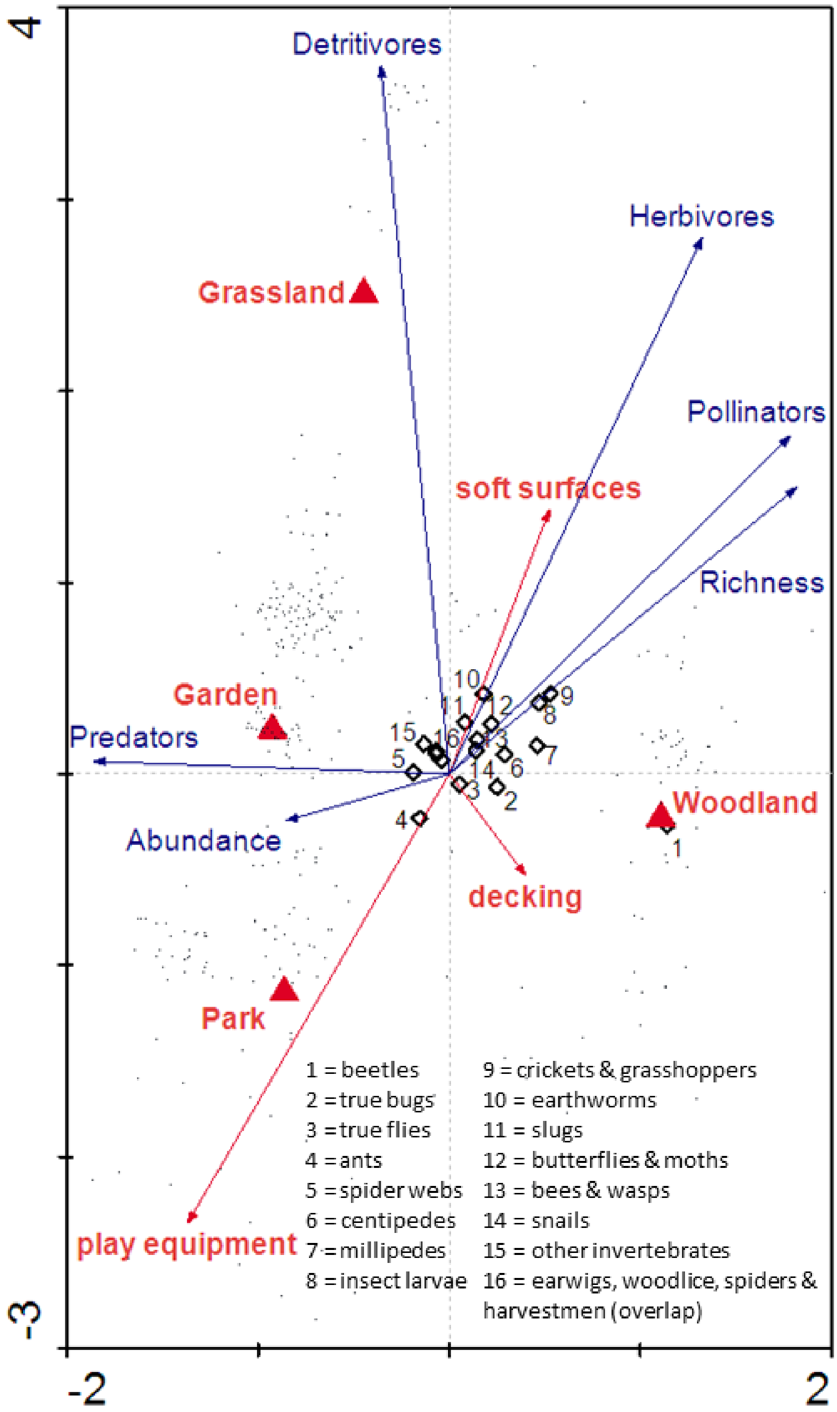

1 = woodlice
2 = crickets & grasshoppers
3 = insect larvae
4 = butterflies & moths
5 = true flies
6 = bees & wasps
7 = other invertebrates
8 = spiders & harvestmen
9 = slugs
10 = snails
11 = true bugs
12 = earwigs
13 = millipedes
14 = earthworms
15 = centipedes
16 = beetles
Park
Pollinators
Grassland
soft surfaces
deprivation
large objects
Total abundance
Garden
Richness
leaf litter
deadwood
Herbivores
Detritivores
Woodland
Predators
3
-2
-2
2

Fig. 1.


4
-3
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Detritivores
Herbivores
Grassland
Pollinators
soft surfaces
Richness
Garden
Predators
Woodland
Abundance
decking
Park
play equipment
1 = beetles
2 = true bugs
3 = true flies
4 = ants
5 = spider webs
6 = centipedes
7 = millipedes
8 = insect larvae
9 = crickets & grasshoppers
10 = earthworms
11 = slugs
12 = butterflies & moths
13 = bees & wasps
14 = snails
15 = other invertebrates
16 = earwigs, woodlice, spiders & harvestmen (overlap)

Fig. 2.