

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

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39 ABSTRACT

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

60

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

63

64 **Introduction**

65 The diversity and number of citizen science projects is burgeoning. This is in part
66 because citizen science can offer two important advantages over traditional professional
67 science: (1) more data can be gathered over larger scales of space and time, including from
68 areas otherwise difficult to study (e.g. private property); and (2) the scientific literacy and
69 awareness of participants can be increased, which can potentially help equip communities
70 with the knowledge to better engage with scientific discourse (Cohn 2008, Bonney et al.
71 2009, Miller-Rushing et al. 2012, Toogood 2013). The Open Air Laboratories (OPAL) citizen
72 science project (OPAL 2012) was launched across England in 2007 and aimed to enhance
73 understanding and enjoyment of the local natural environment, mainly through community
74 participation in environmental science surveys (Davies et al. 2011). The sixth survey,
75 managed by OPAL and the Natural History Museum, was entitled Bugs Count (OPAL 2011)
76 and focused on the effects of urbanisation and habitat characteristics on all higher terrestrial
77 invertebrates, with counts of broad taxonomic groups and six target species that were likely
78 to be affected by urbanisation.

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

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

102 The Bugs Count project focuses on identifying assemblages of higher invertebrates to
103 a relatively low taxonomic resolution, together with six individual species that could be
104 identified easily from photographs. This allowed species-specific responses to urbanisation to
105 be compared with the response of broader invertebrate assemblages. There were several
106 reasons why invertebrates were chosen for this survey. Invertebrates have been termed ‘the
107 little things that run the world’ (Wilson 1987) and are key components of any ecosystem,
108 occupying a spectrum of trophic levels and niches (McIntyre et al. 2001, Prather et al. 2013).
109 Following the framework of the Millennium Ecosystem Assessment (2005), invertebrates
110 influence the following ecosystem services (e.g. Hunter and Hunter 2008, Prather et al.
111 2013): (1) diverse supporting services (e.g. soil formation, nutrient cycling, and pollination);
112 (2) limited provisioning services (e.g. honey and wax production, and genetic resources); (3)
113 diverse regulating services (e.g. altering soil hydrology, pest control, and disease regulation);

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

125 A wide variety of factors can potentially influence urban invertebrate assemblages
126 relative to surrounding rural areas, including increased air and soil pollution of some
127 pollutants, soil nutrient enrichment and compaction, number of exotic plants, light pollution,
128 irrigation, impervious land cover, CO₂ levels, growing season (urban heat island effect),
129 precipitation; and reduced predation pressure, wind speeds, and permeable land cover
130 (Shochat et al. 2006, Grimm et al. 2008, Pickett et al. 2011). Such a diversity of potentially
131 interacting effects makes the effects of urbanisation on invertebrates difficult to predict.
132 Urbanisation is known to generally reduce the species diversity of invertebrates (McKinney
133 2008), but patterns can differ due to the geography and historical development of each urban
134 area (Sadler et al. 2006). Knowledge and understanding of the effects of urbanisation on all
135 groups of higher invertebrates is far from complete. There is a small but increasing body of
136 knowledge for some groups e.g. butterflies (e.g. Di Mauro et al. 2007, Bergerot et al. 2010,
137 Deguines et al. 2012), beetles (e.g. Niemelä and Kotze 2009), bees (e.g. Bates et al. 2011,
138 Deguines et al. 2012, Verboven et al. 2014), ants (e.g. Buczkowski and Richmond 2012);

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

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

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

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

161

162 **Methods**

163 *The OPAL and Natural History Museum Bugs Count survey*

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

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

185 The Species Quest information sheet covers information on the identification of six
186 key study species described below, together with details of where to upload or email digital
187 photographs for identification confirmation. An additional method of recording Species
188 Quest data was added in September 2011 with the launch of Apple ® and Android TM Apps,

189 which allowed instant submission of photographs of the Species Quest invertebrates. The
190 free apps were downloaded over ten thousand times in the first year.

191 *Method standardisation*

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

209 Participants were allowed to survey as large an area as they liked, but asked to spend
210 exactly 15 minutes doing the survey for each of the three challenges. Invertebrates found had
211 to be identified *during* the fifteen minutes. Sample effort was therefore standardised as far as
212 practicable by time, rather than area. This would lower barriers to participation for those
213 people with access to only small potential survey areas. Participants were asked to complete

214 questions on environmental explanatory variables outside of the fifteen minutes. In order to
215 gather information on search effort, participants were asked to record how many people were
216 in their survey team. Relatively few participants answered this question, and when they did,
217 it was not clear whether all members of the team were actively searching for invertebrates,
218 whether some were searching and others recording the data, or whether the majority were
219 watching/learning from a group leader (e.g. teacher) who was doing most of the active
220 searching. Therefore the group size variable could not be used in further analyses.

221 *Study taxa – Challenges 1-3*

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

233 *Explanatory environmental variables – Challenges 1-3*

234 Full details of the questions asked to generate environmental explanatory variables
235 can be found at OPAL (2011). Questions were designed to be as short and unambiguous as
236 possible. Some samples were associated with explanatory variable categories with a small
237 number of observations. Such categories were either amalgamated into larger categories or
238 removed from further analyses (together with the associated samples). Data from June 2011

239 to May 2012 were analysed. December 2011, January 2012, and February 2012 had a small
240 number of observations so were removed from subsequent analyses. June - August 2011,
241 September - November 2011, and March - May 2012 were classed as the categorical dummy
242 variables 'summer', 'autumn', and 'spring' respectively. There were few observations from
243 streets/estates, waste grounds, and 'other' habitats, so these data were removed from
244 subsequent analyses, leaving four study habitats: woodland, gardens, park, and grassland.

245 Table 2 shows the explanatory variables used in analyses. Additional explanatory
246 variables were created using the postcodes provided by participants, namely latitude and
247 longitude (in decimal degrees), Index of Multiple Deprivation (IMD) score (ranking of
248 deprivation of seven types e.g. employment, health and education), and urbanisation
249 (urban/rural indicators URI). The IMD and URI data were downloaded from GeoConvert
250 (2012). Postcodes were matched to Lower Super Output Areas to get IMD data from the
251 Indices of Deprivation 2007. URI codes were used to associate postcodes with 'urbanized'
252 (urban and suburban areas of towns and cities, URI codes 1, 2, 5, and 6) and 'rural'
253 (countryside, hamlets and villages, URI codes 3, 4, 7, and 8) areas.

254 *Challenge 1-3 data quality control*

255 Misidentification of study taxa is a potential problem associated with ecological
256 citizen science data, but careful data validation and error checking can help reduce the
257 amount of erroneous data (e.g. Bonney et al. 2009, Bone et al. 2012, Bonter and Cooper
258 2012, Deguines et al. 2012). The Bugs Count survey asked participants 'who are you doing
259 the activities with today?' with participants able to answer: (1) primary school, (2) secondary
260 school, (3) other youth group, (4) college/university, (5) adult volunteer group, (6) family or
261 friends, or (7) on your own. The answers were used to assume that most of those who
262 answered: 1 = children <12 years old, 2 and 3 = 12-17 years old, and 4-7 = >17 years old. It

263 also asked participants 'have you identified invertebrates before' with participants able to
264 answer yes or no.

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

280 In addition to sample weighting according to likely identification accuracy, samples
281 were cleaned in a data rationalisation process, where likely erroneous or duplicate entries
282 were removed. It was clear from the answers to questions on habitat and reported abundances
283 of certain taxa that a small number of participants were searching for invertebrates in areas
284 outside the microhabitats described for an individual challenge (for example, samples for
285 Challenge 2 [hard surfaces] that reported the survey area to be all soft surfaces, or samples
286 for Challenge 3 [plants] that reported large counts of earthworms). Such samples were
287 removed from analyses. Some samples included counts far in excess of other counts of the

288 same taxa (e.g. >100 beetles, >80 crickets/grasshoppers, >280 spider webs) and were
289 considered likely errors relative to the other data and in the experiences of the authors, and so
290 were removed (see also: Bonney et al. 2009, Bonter and Cooper 2012). Counts of true bugs
291 for Challenge 3 (plants) were problematic because some participants were including aphids
292 while some participants were not, so true bug counts were excluded from this analysis.
293 Counts of ants were also problematic, being strongly bimodal depending on whether a nest
294 was/was not discovered in the survey area. In addition, their large abundances can swamp
295 abundance patterns in other taxa (e.g. McIntyre et al. 2001). Counts of ants were excluded
296 from analyses of Challenge 1 (soft) and Challenge 3 (plants) data.

297 *Challenge 1-3 data analyses*

298 Data were analysed using ordination of the three separate datasets in Canoco for
299 Windows version 4.51 (ter Braak and Šmilauer 1998). Ordination is a method of
300 summarising multivariate data, so that multidimensional information can be reduced to two
301 dimensional information that can be more easily visualised and interpreted. Counts of
302 individual taxa were used as the ‘species’ response data. Total abundance, richness of taxa,
303 total pollinators, herbivores, and detritivores were used as supplementary variables (i.e.
304 passive variables, with patterns shown on ordination diagrams, but which do not affect the
305 ordination statistics). Latitude, longitude, season, and weather were used as covariables (i.e.
306 included within the ordination statistics, but not the focus of the investigation, so not shown
307 on ordination diagrams). Site, IMD score, soft surfaces, total microhabitats, and individual
308 microhabitats were used as explanatory environmental variables. Age and experience weights
309 were multiplied to create combined sample weights for use in the analyses (Table 2). The
310 gradient lengths from preliminary indirect ordinations using partial detrended correspondence
311 analyses (pDCAs) were all long (largest >4, all >3) so partial canonical correspondence
312 analysis (pCCAs) was the preferred method (Lepš and Šmilauer 2003). Scaling was by inter-

313 species distance with Hill's scaling. Environmental variables ($P < 0.05$) were selected using
314 manual forward selection using Monte Carlo simulations under the full model (9999
315 unrestricted permutations and a random seed).

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

323 *The Species Quest data*

324 While participating in the Bugs Count challenges, or separate from these challenges,
325 people were asked to report sightings of six species of invertebrate: Two-spot Ladybird
326 (*Adalia bipunctata* (Linnaeus, 1758)), Devil's Coach Horse (*Ocypus olens* (Müller, O.F.,
327 1764)), Small Tortoiseshell (*Aglais urticae* (Linnaeus, 1758)), Green Shieldbug (*Palomena*
328 *prasina* (Linnaeus, 1761)), Leopard Slug (*Limax maximus* Linnaeus, 1758), and Tree
329 Bumblebee (*Bombus hypnorum* (Linnaeus, 1758)). Given the relative difficulty of identifying
330 these species for those with little identification experience, only records with attached
331 photographs (e.g. Deguines et al. 2012) showing correctly identified individuals were used in
332 further analyses. For the most part, these records were individual records with a date and
333 location but no other associated environmental information, rather than being observations
334 associated with a Bugs Count survey.

335 To test whether each species showed evidence of favouring urbanized (urban and
336 suburban areas) or rural sites, records were classified as urbanized or rural (countryside or
337 villages less than 1x1 km) using Google Earth by AJB. Multiple records from the same site

338 were removed to leave one record for each site, so that records indicated presence at that site.
339 A test of homogeneity of observations would expect to find an equal number of observations
340 in urbanized and rural areas if the target species showed no preference for urbanized and rural
341 areas, and if sampling effort was equal between urbanized and rural areas. However, there
342 was clearly more sampling effort in urbanized areas, where 344 observations were made,
343 compared to 189 observations in rural areas (this was fairly typical of OPAL projects overall
344 as a consequence of the distribution of OPAL staff, and population concentration in urban
345 areas). Therefore, for each of the six target species, the summed ratio of urbanized to rural
346 observations in the remaining five species was used as a proxy for sampling effort to predict
347 the expected ratio in the target species. Differences between the observed and expected
348 frequencies of urbanized to rural sites were tested for significance using χ^2 two-category
349 goodness of fit tests.

350

351 **Results**

352 *Comparisons between the three challenges*

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

363 *Challenge 1: soft surfaces*

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

373 *Challenge 2: human-made hard surfaces*

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

382 *Challenge 3: plants*

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

386 *Species Quest data*

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

393 **Discussion**

394 *Data quality*

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

405 Nevertheless, there were inevitably some systematic errors and erroneous samples in
406 the dataset. For example, the counts of predators in the datasets are perhaps unrealistically
407 high, possibly because spider webs and fast moving centipedes are particularly obvious and
408 thus easier to detect, or because it was possible for participants to double count both a spider
409 web and a spider as individual predators. Samples more likely to be erroneous because of the
410 age or experience of participants were down-weighted, and obviously inflated counts could
411 be detected and removed from analyses. However, the detection of erroneously low counts is

412 particularly difficult. Such counts could either be genuine due to, for example, limited habitat
413 availability or poor weather conditions, or erroneous, due to a poorly motivated participant or
414 one unwilling to disturb garden vegetation. The inevitability of having some errors in a
415 citizen science dataset is offset by the large sample pool (large n), which creates a favourable
416 signal to noise ratio and thereby reduces the influence of errors in the overall findings
417 (Bonney et al. 2009, Bonter and Cooper 2012). Nonetheless, we consider citizen science
418 projects of the form employed in this study that had very few limits to participation, to
419 perhaps be best suited for scoping broad trends that can then be explored in later, smaller-
420 scale studies (see also discussion in Bonney et al. 2009). In other words, it is perhaps more
421 suitable for hypothesis generation, rather than hypothesis testing.

422

423 *Effect of local habitat*

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

435

436 *Effect of urbanisation*

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

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

455 Predicting the effects of altered assemblage on trophic dynamics and functionality is
456 difficult (Faeth et al. 2005, Hooper et al. 2005). Although large differences have been found
457 between urban and rural areas in desert ecosystems due to urban watering (Faeth et al. 2005),
458 in temperate areas, differences might be expected to be more subtle. Due to functional
459 redundancy, whereby several species perform similar functional roles, many ecosystem
460 services can be robust to the effects of species loss (e.g. Memmott et al. 2004, Hooper et al.
461 2005). Our preliminary finding of little difference between urban and rural higher

462 invertebrate assemblages and functional/feeding groups, suggests that broad invertebrate
463 facilitated ecosystem services might remain intact in temperate towns and cities. However,
464 the loss of a dominant, keystone, or ecological engineer species can sometimes have a
465 disproportional effect on ecosystem functioning and service provision (Hooper et al. 2005).
466 So the effect of urbanisation on the occurrence and abundance of individual species also
467 needs to be considered.

468 *Species Quest trends*

469 The differing number of observations in urbanized and rural locations for the six
470 study species suggests that, as might be expected, responses to urbanisation are species-
471 specific. Five of the six species showed some detectable response to urbanisation, with three
472 species commoner in rural areas, and two species commoner in urbanized areas. However,
473 given the many possibilities for sampling bias associated with the methods, we adopted
474 $P < 0.01$ as a more conservative threshold for statistical significance, and only discuss further
475 the trends for Small Tortoiseshell (*Aglais urticae*) and Tree Bumblebee (*Bombus hypnorum*).

476 Once common and abundant, Small Tortoiseshell has declined in recent years across
477 The Netherlands (Van Dyck et al. 2009) and the UK (Fox et al. 2011), and may well have
478 declined in other highly developed landscapes across its range (all of Europe and most of
479 Asia). Van Dyck et al. (2009) found the decline to be stronger in urban areas, suggesting that
480 this species is negatively associated with urbanisation, supporting our own findings. In
481 Switzerland, Altermatt (2012) found that the first appearance (25% of individuals observed
482 during the flight period per year) of Small Tortoiseshell was nearly 20 days later in (warmer)
483 settlement habitats than (cooler) agricultural habitats. The preferred display and oviposition
484 sites of Small Tortoiseshell are sunlit, containing nettles (larval foodplant and roost), by the
485 edge of a wall or hedge (Baker 1972), and although this combination of microhabitats occurs
486 in urbanized areas, suitable habitats are more likely to be found in rural areas. These findings

487 suggest that the larval, breeding, and overwintering microhabitats of Small Tortoiseshell are
488 likely to be mainly outside urbanized areas, with adults (possibly the second brood
489 particularly) dispersing to urbanized areas randomly during nectar foraging bouts, when they
490 move in a relatively straight line related to the azimuth of the sun (Baker 1968). These factors
491 would explain the negative association with urbanized areas found in the Species Quest data.

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

499 *Implications for citizen science projects*

500 Not all citizen science projects include systems to check data quality (Crall et al.
501 2010), but as shown in this and other studies, systems to manage citizen science data quality
502 are essential (Cohn 2008, Bonney et al. 2009, Bonter and Cooper 2012, Miller-Rushing et al.
503 2012). Our study shows that even low barrier to entry citizen science can deliver useful and
504 biologically interpretable results, but this was only achieved in this instance through
505 retrospective data rationalisation and weighting according to age and experience. Other
506 studies (e.g. Bonney et al. 2009; Bonter and Cooper 2012) have used automatic filters to
507 identify potential errors in data entry and to encourage entry of all necessary data. Such
508 approaches should be encouraged when they do not compromise participation, such as on-
509 line automatic unusual data entry warnings, that still allow the entry of unusual data if the
510 participant chooses (e.g. Bonter and Cooper 2012).

511 Taking part in citizen science projects can alter the behaviour and improve the
512 scientific literacy of participants (Bonney et al. 2009, Miller-Rushing et al. 2012, Toogood
513 2013), so participation by as many people as possible should be encouraged where this is part
514 of the aim of the citizen science project. Data that are likely to be of poorer quality due to
515 participant age, background, or experience can be weighted accordingly so that confidence
516 can be maintained in the findings without too much data loss. This approach does, however,
517 require the collection of demographic and level of experience data and supporting studies of
518 how these factors affect data quality.

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

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

533

534 **Conclusions**

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

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

552

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563

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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).

Species	Observed		Count of other 5 spp.		Prop. of other 5 spp.		Expected		Trend	χ^2	Significance
	Urbanized	Rural	Urbanized	Rural	Urbanized	Rural	Urbanized	Rural			
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

List of Figures

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.

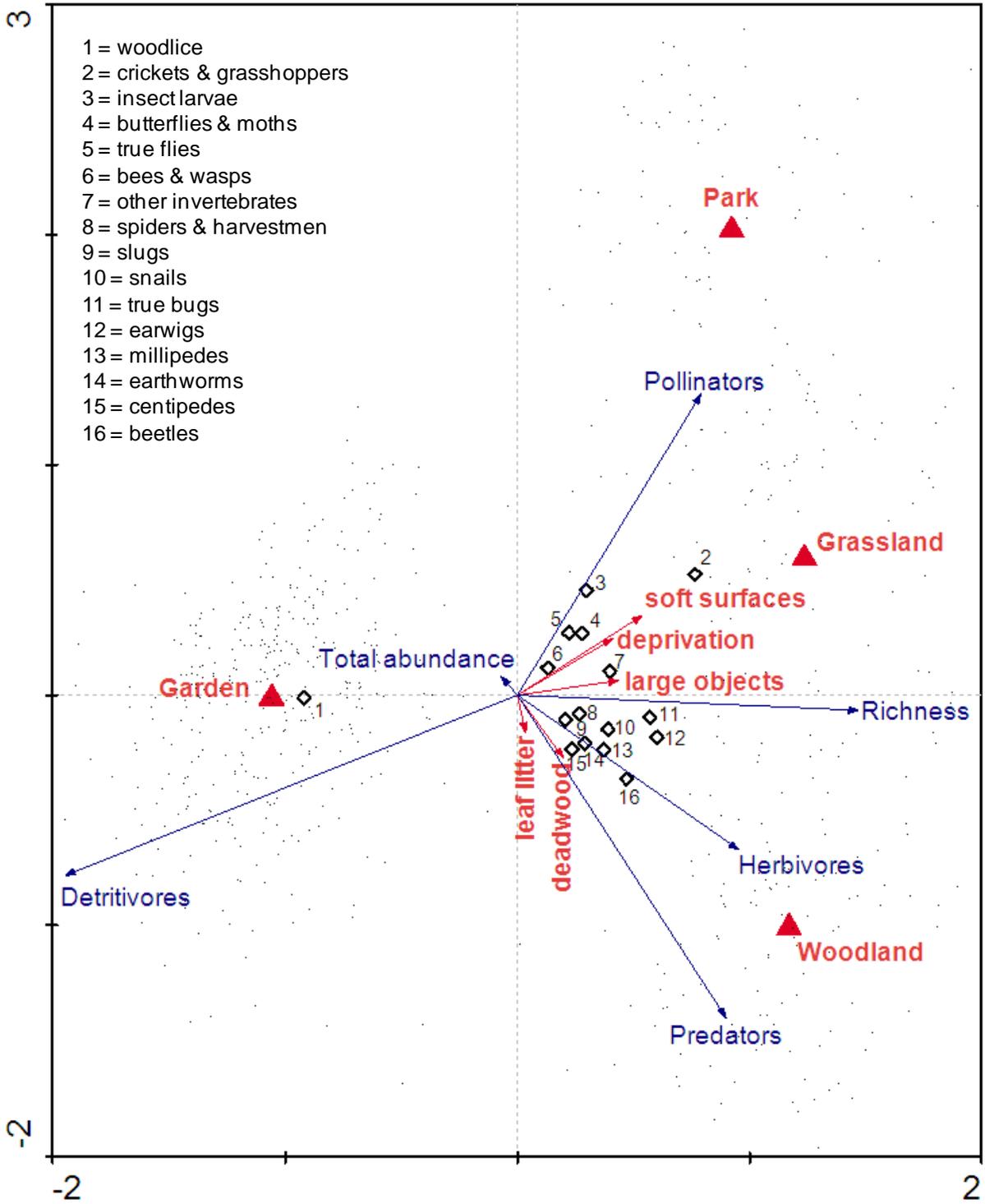


Fig. 1.

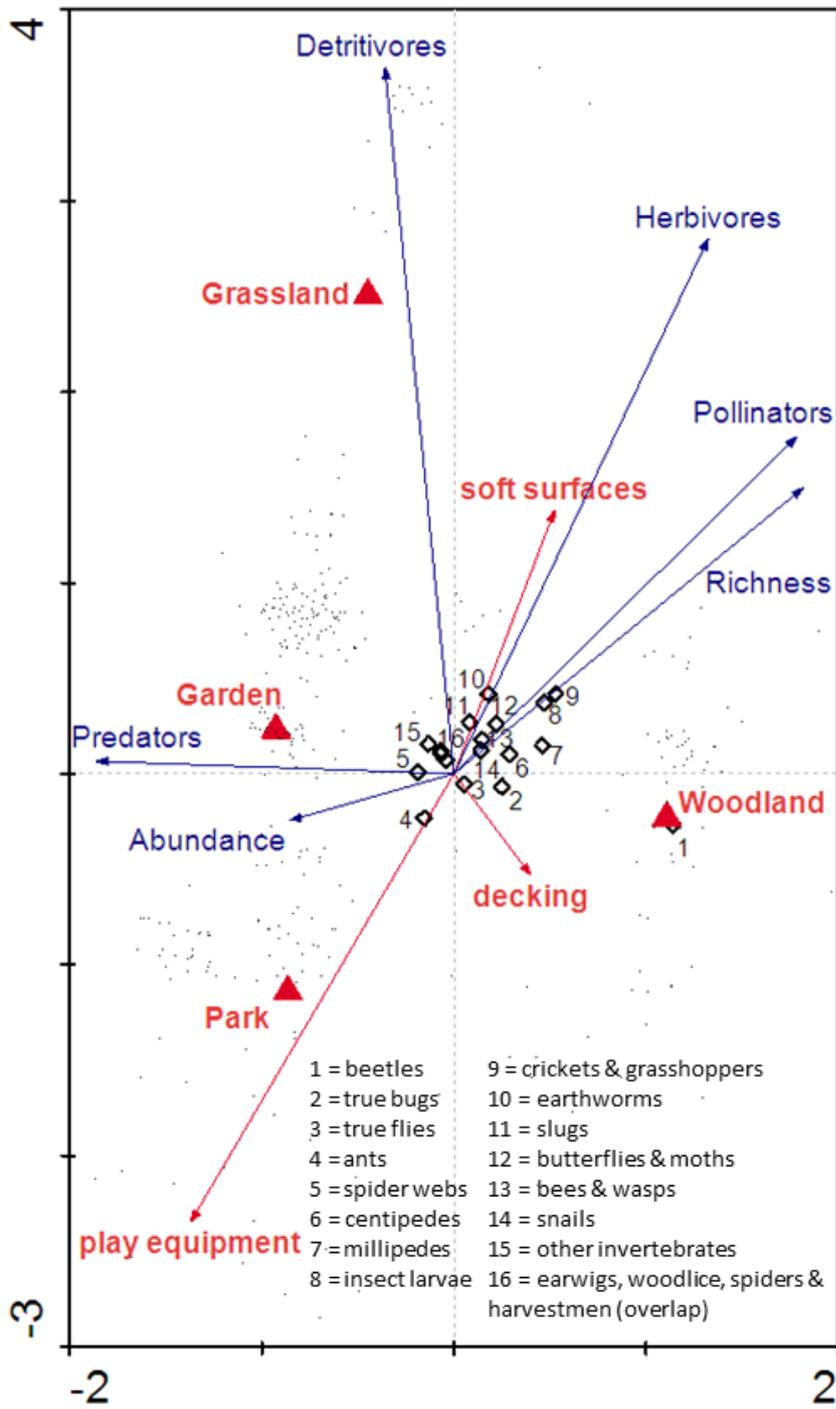


Fig. 2.