An Evaluation of Community-based Monitoring of Biodiversity in Greater London

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1. Abstract

The collective monitoring of biodiversity by community groups in Greater London has great potential toward scientific and management goals. However, issues such as gaps in spatial and temporal coverage, uneven taxonomic representation and poor data sharing can limit its utility. An evaluation of community-based monitoring (CBM) is thus crucial to identify opportunities for effective use of the data. To achieve this, an online questionnaire and semi-structured interviews were used to collect data on CBM surveys and motivations of community groups in Greater London. Community group records stored by the biological records centre of London were also examined. 90 of 556 community groups (16.1%) responded to the questionnaire, of which 47 (53.5%) conduct CBM. These groups provided data on 119 monitoring surveys. Contrary to previous suggestions, a large proportion (56.2%) of the surveys utilised standardised protocols. Top-ranked motivation for with conducting monitoring surveys was significantly associated with local nature conservation (χ^2 test: df=3, n=90, χ^2 = 13.60, P=0.003). Analyses of questionnaire responses and GiGL records showed extreme unevenness in spatial and temporal coverage of CBM among taxonomic groups, precluding applications of CBM involving general biodiversity. CBM datasets were best for Birds, Butterflies and Other Invertebrates and might be suitable for uses in research and management in Greater London.

2. Introduction

The rapid replacement of natural habitats with urban landscapes worldwide has led to an increasing need for effective management and research of biodiversity within and around cities (Marzluff 2001; Shochat et al., 2006). By providing crucial data and evidence, the monitoring of urban biodiversity can be extremely useful toward achieving these objectives (Yoccoz et al., 2001; Hutto & Belote, 2013). Despite the benefits of monitoring, professional monitoring efforts are often constrained due to limited manpower. Volunteers therefore have an important role in augmenting overall monitoring efforts (Dickinson et al, 2010; Forrester et al., 2015). Community groups, in particular, have voluntarily collected biological data for decades in the United Kingdom (UK) (Miller-Rushing et al., 2012). The combined dataset of these groups is potentially large and useful for various applications in the monitoring of urban systems. Within the UK, these community-based monitoring (CBM) data is pooled from individual, dispersed community groups into biological records centres (BRCs) to facilitate use of the collective data (Fig.1).

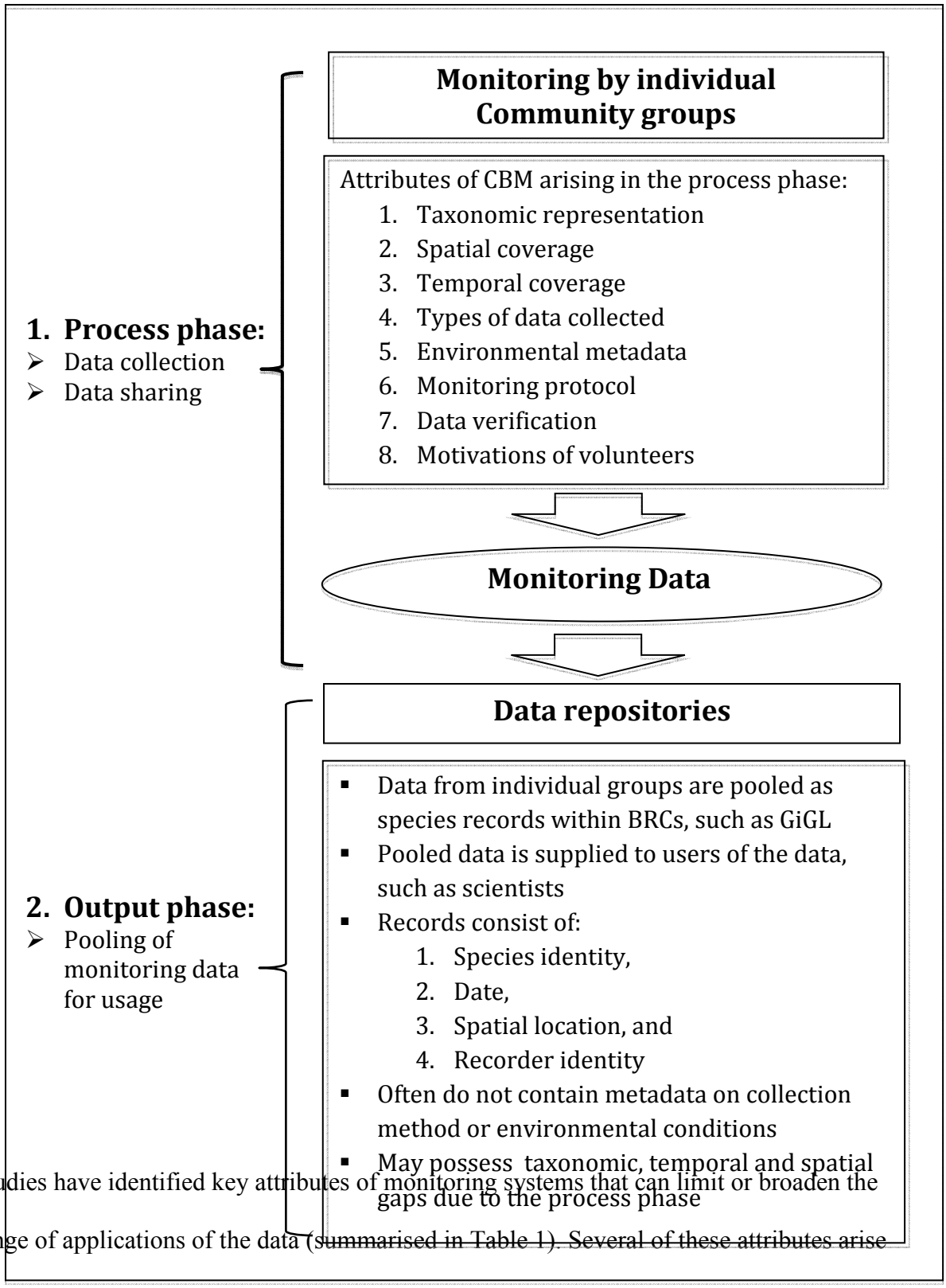


Figure 1. Conceptual diagram of the collaborative system of community-based monitoring in Greater London. The system involves two phases: a process phase, in which data is collected and shared, and an output phase, in which data is pooled and used. Adapted from Gouveia et al. (2004).

Studies have identified key attributes of monitoring systems that can limit or broaden the range of applications of the data (summarised in Table 1). Several of these attributes arise within the *process* phase of monitoring, which comprises data collection and data sharing (Fig.1). Negative attributes that arise in this phase include gaps in monitoring coverage across space and time, and an uneven taxonomic representation (Snäll et al., 2011). Conversely,

positive attributes such as collecting environmental metadata can improve the data's utility (Bird et al., 2014; Isaac et al., 2014). As CBM is conducted by non-professionals, attributes such as having a standardised monitoring protocol and data verification are also important as they affect the data's reliability (Conrad & Hilchey, 2011). Motivations are also crucial as they can determine how groups conduct monitoring and whether they share data. Data sharing is also necessary for the data to be accessible to scientists and decision-makers. In the *output* phase of CBM, one negative attribute is the absence of metadata on collection method or environmental conditions for the vast majority of CBM data that is stored (Fig.1; Madin et al., 2007). Lack of such metadata limits the range of applications of CBM data (Gouveia et al., 2004; Kelling et al., 2009). An understanding of these attributes of CBM across both the process and output phases is therefore needed to effectively use the monitoring data (Tulloch et al., 2013).

This study thus seeks to critically evaluate the system of CBM in Greater London, in order to identify opportunities for effective use of the data toward research and management of urban biodiversity. To draw inferences on the attributes listed in Table 1, I investigate the process phase of CBM of London by examining a sample of monitoring surveys conducted by community groups. Although community groups can collect monitoring data through non-survey methods, such as by collating opportunistic sightings, I focus solely on surveys as they present an opportunity for additional metadata on methods, spatial and temporal coverage to be feasibly obtained and compiled (Dickinson et al., 2010).

In addition, attributes such as uneven taxonomic representation and gaps in spatial or temporal coverage of CBM can also leave a signature in CBM datasets (Fig. 1). I therefore draw additional inferences on these three attributes within the output phase of CBM by

examining CBM data stored by the BRC of Greater London, the Greenspace Information for Greater London (GiGL).

Table 1. Summary of attributes of monitoring programmes that affect utility of the resulting data.

Attribute	Implications on utility	References
a) General ecological monitoring programmes		
Evenness of taxonomic representation	Affects the data's representativeness of the regional biodiversity	Schmeller et al., 2009; Pereira & Cooper, 2006
Extent of spatial coverage	Affects the geographic area in which the data can be applied	Gouveia et al., 2004; Sullivan et al., 2009; Snäll

		et al., 2011; Isaac & Pocock, 2015
Extent of temporal coverage	Affects the time period in which the data can be applied	Gouveia et al., 2004; Sullivan et al., 2009; Tweddle et al., 2012; Dornelas et al., 2013
Types of data collected (e.g. presence-only vs presence-absence)	Affects the data's ability to deal with detection error	Schmeller et al., 2009; Snäll et al. 2011; Isaac & Pocock, 2015
Collection of environmental metadata	Affects the data's ability to control for environmental conditions	Madin et al., 2007; Isaac & Pocock, 2015
b) Monitoring programmes involving non-professionals		
Standardisation of monitoring protocol	Affects the data's reliability and types of inferences possible	Snäll et al., 2011; Newman et al., 2012; Isaac & Pocock, 2015; Bonney et al. 2009
Data sharing	Affects sample size of dataset	UKEOF, 2011; Baker et al., 2012; Newman et al., 2012; Tweddle et al., 2012
Data verification for accuracy	Affects data's reliability	Conrad & Hilchey, 2011; Snäll et al., 2011; Gardiner et al., 2012; Bonter & Cooper, 2012
Motivations of volunteers	Affects how monitoring is conducted, and whether the data is shared	Couvet et al., 2008; Hobbs & White, 2012; Roy et al., 2012; Wolcott et al. 2008

3. Methods

3.1 Study area

This study focuses on CBM within Greater London, an area in the United Kingdom that comprises of 32 London Boroughs and the City of London. Greater London has a total area of 1537km^2, and a population of 8.2 million at the most recent census (Office for National Statistics, 2011).

3.2 Research approach

This research employs two methods to infer the state of attributes from the process phase of CBM (Fig.1), and a third method to independently examine the output phases of CBM (Table 2). The first two methods, an online questionnaire and semi-structured interviews, were chosen to obtain quantitative data and qualitative insights on monitoring surveys conducted by a large number of community groups. Within this study, I define a 'monitoring survey' as "any activity that collects data to make inferences on temporal changes in biodiversity", following the definition of monitoring by Yoccoz et al. (2001). The third method involved analyzing a dataset of CBM records stored by GIGL. I refer to this dataset as the 'GiGL records'.

Table 2. Data sources and variables used to investigate attributes of CBM within the two phases of CBM in Greater London. Sample sizes (*n*) are indicated.

Phase	Data source	*n*	Variables analysed
Process of CBM	Online questionnaire responses	90	1. axonomic groups 2. ocation of surveys 3. abitats surveyed

			4. urvey methods 5. tandardised vs *ad-hoc* protocol 6. ength of monitoring 7. ypes of data collected 8. nvironmental data collected 9. roup motivations (ranked) 10. erification of data 11. ata sharing 12. rganiser of surveys
	Semi-structured interviews	6	13. roup motivations 14. sage of monitoring data 15. hallenges to monitoring
Output of CBM	GiGL records submitted by community groups	849251	16. axonomic representation of records 17. patial coverage of records 18. emporal coverage of records

3.3 Data collection

Collecting data on the process phase of CBM in Greater London involved six steps: 1) key informant interviews, 2) compiling a comprehensive contact list of community groups that might conduct biodiversity monitoring within Greater London, 3) developing an online questionnaire, 4) piloting and distributing the questionnaire, 5) managing questionnaire responses, and 6) conducting semi-structured interviews.

3.3.1 *Key Informant interviews*

Key informant interviews were conducted with representatives of three organisations that work with CBM in Greater London (Table 3). These interviews provided insights into CBM, which were used to structure questionnaires.

Table 3. Key informants interviewed.

Informant	Role
Kingston Biodiversity Network	Collaborates with other local groups within Kingston Upon Thames to conduct CBM activities.
Greenspace Information for Greater London (GiGL)	The local environmental records center for London.
Open Air Laboratories Network	A UK-wide initiative that develops citizen-science nature surveys

3.3.2 Compiling contacts

A systematic internet search was conducted to compile a list of community groups which undertake nature-related activities within Greater London. I defined a 'community group' as "any organization that is not led by academic or governmental institution". The searches were done via Google UK (www.google.co.uk) using the search terms 'group'; 'nature'; 'wildlife'; 'community'; 'Greater London'; 'volunteer'; 'monitoring', and via online group-finder tools hosted by the Royal Society for the Protection of Birds and the Natural History Museum of London (RSPB, 2015; NHM, 2015). The search found 595 community groups, but 39 were excluded due to lack of contact details. The final contact list thus consisted of 556 groups.

3.3.3 Online questionnaire design

Next, an online questionnaire for community group representatives was developed. The aim of the question was to identify groups that conduct CBM and to gather information on surveys. This was achieved using the web-based software Qualtrics (http://www.qualtrics.com/) using its functionality to show different sections based on the respondent's answers. This allowed it to cater to groups regardless of whether they conduct biodiversity monitoring.

The first section of the questionnaire captured group information, such as the group's main activities, and to rank its primary motivations. Crucially, respondents were required to indicate whether the group conducts monitoring surveys, according to a provided definition. If the respondent indicated that group undertakes surveys, the questionnaire flowed to the second section, which captured information on these surveys (summarised in Table 2), for a maximum of three surveys. This limit was imposed to keep the questionnaire short and improve response rate (Milner-Gulland & Rowcliffe, 2007). Respondents who indicated that their group does not undertake surveys were instead led to a question asking them to describe the group's activities in further detail. This enabled me to check that the question was not misinterpreted. To allow for follow-up, all respondents were required to provide their name, contact details, and position in their group.

The questionnaire was piloted with three volunteer groups, and subsequently edited for clarity and adequacy. The final version contained 30 item open-ended or multiple-choice questions and one ranked question, and took about 15 minutes to complete (Appendix 1).

3.3.4 Distribution of questionnaires

A link to the questionnaire was delivered to the contact list with an introduction to the research via email, telephone, and online contact forms. As the internet search may not have detected all CBM groups, such as those without websites, I also requested all contacted groups to circulate the questionnaire within their individual networks. This same request was made to organisations that work with volunteer groups in London, such as the London Wildlife Trust, Zoological Society of London, and BRCs, such as GiGL and the National Biodiversity Network. The questionnaire was active for responses between 30 April and 10 May 2015.

3.3.5 Managing of questionnaire responses

I checked completeness of questionnaire responses and made attempts to re-contact groups to obtain missing information. Complete responses were not possible for all CBM surveys, however, and thus the sample sizes varied among analyses.

3.3.6 Semi-structured interviews

I contacted six survey respondents for semi-structured telephone interviews between 11 May and 17 May 2015. The interviews explored the group's motivations and challenges faced in relation to monitoring. The six groups were chosen to represent the diversity of scopes of their activities (Table 4). 'Local groups' were defined as groups which restrict their monitoring to a specific site, such as a park.

Table 4. List of groups interviewed for case-studies.

Group	Scope
Friends of Queen's Wood	Local
Barnet Local Group	Local
Bexley Natural Environment Forum	Borough
Kingston Biodiversity Network	Borough
Essex Field Club	County
London Natural History Society	County

3.4 GiGL records

Through a license agreement with GiGL, I obtained a dataset of 849,251 species records made within Greater London and submitted by 19 community groups (Appendix 2). Each record contains the date, group name, and location in 1-km spatial resolution. While some submitted records have yet to be added to GiGL's database, it was the most complete CBM dataset available for Greater London as of April 2015 (C. Smith 2015, pers. comm., 6 May).

3.5 Analyses using questionnaire responses and GiGL records

To examine the standardization of CBM survey methods, I distinguished 'standardised surveys', in which a protocol was consistently followed to collect data, from '*ad-hoc* surveys', in which no protocol was followed (Cardoso et al., 2009).

As a preliminary examination of the GiGL records found that bats and butterflies were particularly well-represented, I classified the taxa into the following 10 species groups for all analyses of taxonomic representation: 'Amphibians'; 'Bats'; 'Birds'; 'Butterflies'; 'Fish'; 'Fungi & Lichen'; 'Other Mammals'; 'Other Invertebrates'; 'Plants'; and 'Reptiles'. Taxa included in 'Other Mammals' are mammals except bats, while taxa in 'Other Invertebrates' include all invertebrates except butterflies.

To assess spatial coverage of CBM, I used a Geographic Information System (GIS) to plot specific survey sites indicated in the questionnaire responses onto a base map of Greater London. I then calculated the total area of survey sites and examined their spatial distribution across Greater London. The GIGL records were plotted using GIS as 1-km gridsquares for each species group onto a separate map. As a proxy for spatial coverage, I summed the number of 1-km gridsquares containing GiGL records.

To assess temporal coverage of CBM, I used the statistical software 'R' version 3.0.1 (R Core Team, 2015) to determine the mean duration of surveys based on the year the survey started and ended, as indicated in questionnaire responses. I also compared the number of GiGL records that were 'recent' (defined in this study as records in 2000-2015) and 'old' (1950-1999).

To assess evenness in taxonomic representation, I compared the spatial coverage, temporal coverage, and number of standardised and *ad-hoc* surveys among the species groups based on data from questionnaire responses, and also compared number of GiGl records for each species group.

In separate analyses using questionnaire responses, I calculated the proportion of surveys that conduct data verification; collect environmental data; and share data with other organisations. The proportion of surveys for each data type collected, and the proportion of standardised surveys that were externally organised were also calculated. I also examined the variation in numbers of recent and old records made by the 19 community groups that formed the GiGL records.

Lastly, to understand motivations of CBM groups, two chi-square tests were performed to examine if respondents' top-ranked motivations were associated with conducting of surveys or utilizing standardised survey protocols.

4. Results

4.1 Questionnaire responses

A total of 90 responses (16.1%) were returned from the 556 community groups contacted. 47 respondents indicated that they undertake monitoring surveys in Greater London (53.3%), and are thus considered as monitoring groups (Appendix 3). 22 respondents (25.2%) compile sightings of taxa contributed by volunteers, but do not conduct monitoring surveys as a group, and thus were excluded. 20 respondents (23.0%) do not collect ecological data at all.

The 47 monitoring groups provided information on 119 monitoring surveys in total, although data on certain variables were incomplete. 67 of these surveys were standardised (56.3%), while the rest were *ad-hoc.* Only nine surveys (7.6%) collected data on multiple taxonomic groups. 35 of the monitoring groups (74.5%) conduct at least one standardised survey.

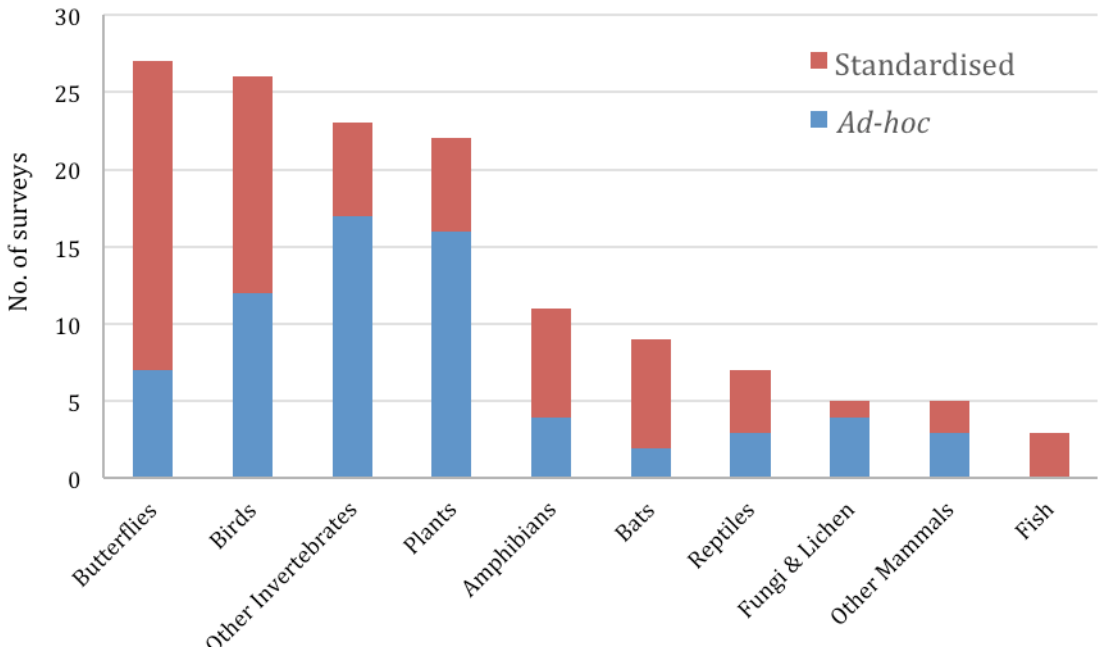
Based on questionnaire responses, we found that 46.8% of the monitoring groups' scopes were local, 38.3% were borough-level, 8.5% were county-level, and 6.4% were national-level.

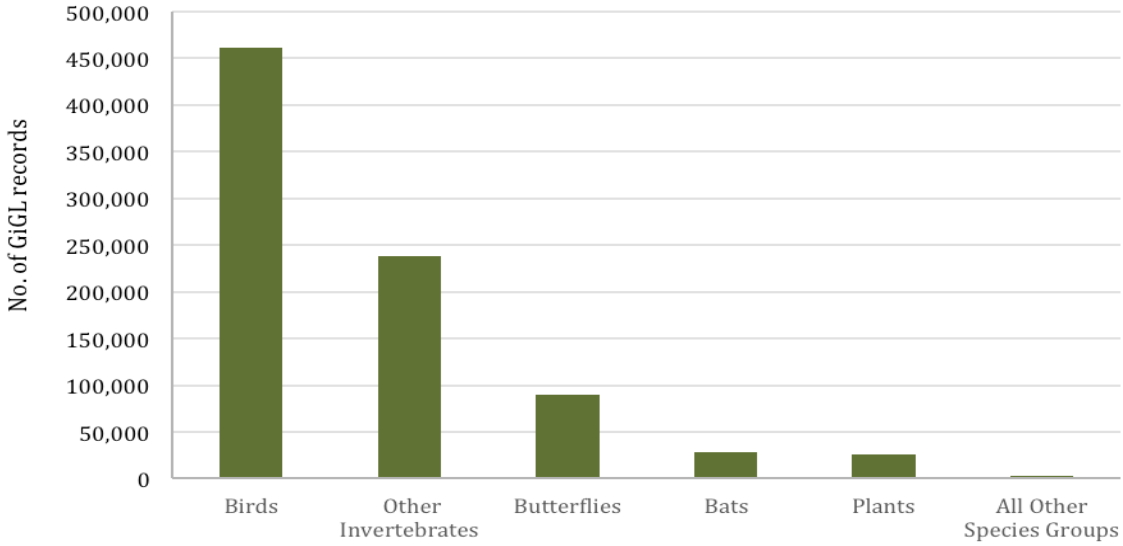
4.2 Numbers of surveys & taxonomic representativeness

Overall, the CBM surveys covered all 10 species groups, but the number of surveys was skewed toward Butterflies, Birds, Other Invertebrates, and Plants (Fig.2). Fish received the lowest total number of CBM surveys (n=3), although they were all standardised. The number of standardised surveys were highest for Butterflies and Birds (n=20 and n=14 respectively), while Fungi & Lichen and Other Mammals received the fewest (n=1 and n=2 respectively). *Ad-hoc* surveys were highest for Other Invertebrates and Plants (n=17 and n=16 respectively), while Fish had none. Overall, more standardised surveys were conducted than *ad-hoc* surveys for six of the 10 species groups, with the exceptions being Fungi & Lichen, Other Invertebrates, Other Mammals, and Plants (Fig.2).

The GiGL dataset similarly covered all species groups, but showed a much more extreme taxonomic bias (Fig.3). Vast majority of the record (93.4%) comprised solely of three species groups alone (Birds, 54.4%, *n*=461824; Other Invertebrates, 28.5% *n*=242164; and Butterflies, 10.5%, *n*=89480). The records for remaining seven species groups constituted only 6.6% of the data (*n*=55783).

The pattern in numbers of GiGL records showed congruence with the pattern of variation in number of surveys conducted among species groups (Fig.2, Fig.3), with Birds, Other Invertebrates and Butterflies being the most represented, while Fish, Fungi & Lichen, Other Mammals and Reptiles being the least.



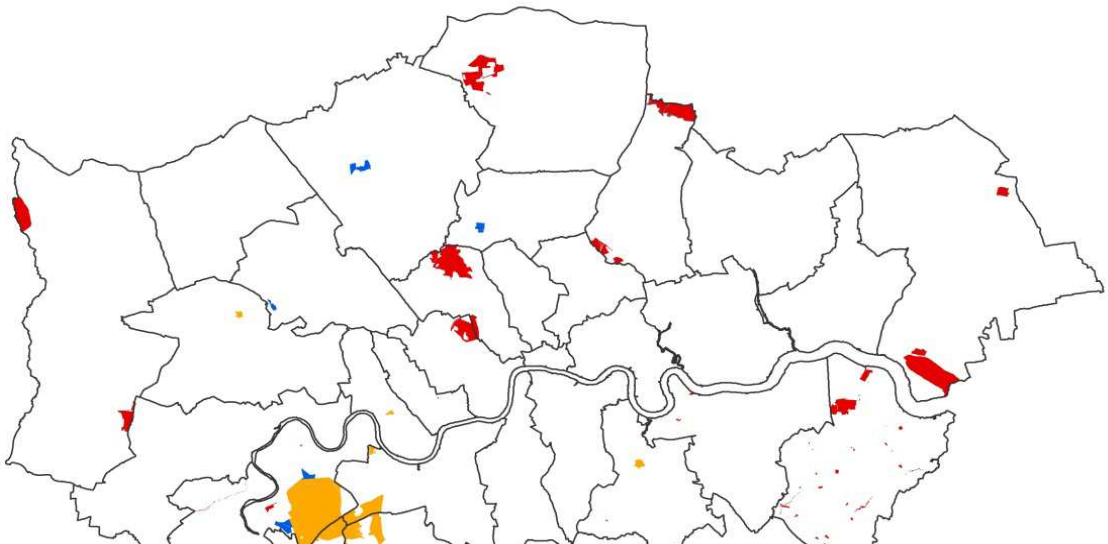


4.3 Spatial coverage of CBM

Specific locations of survey sites were provided for 97 of the 119 monitoring surveys. Collectively, they covered a total area of 38.06 km^2. Standardised surveys covered 89.41% more area than *ad-hoc* surveys, and were more widely distributed across Greater London

Figure 3. Variation in number of GiGL records among the 10 species groups (*n*=849251).

(Fig.4). With the exception of Reptiles and Other Mammals, standardised surveys also covered greater area than *ad-hoc* surveys for all species groups (Fig.5).



Bats, the GiGL records showed a qualitatively congruent pattern in relative spatial coverage among the ten species groups, although the unevenness was even more drastic (Fig.6). The main discrepancy between the area of survey sites and GiGL records was Bats, which showed a relatively high spatial coverage in the GiGL records but relatively low area of survey sites. This could be due to an under-representation of bats survey sites in the questionnaire responses, as four respondents who conduct Bat surveys did not provide information on the locality of sites.

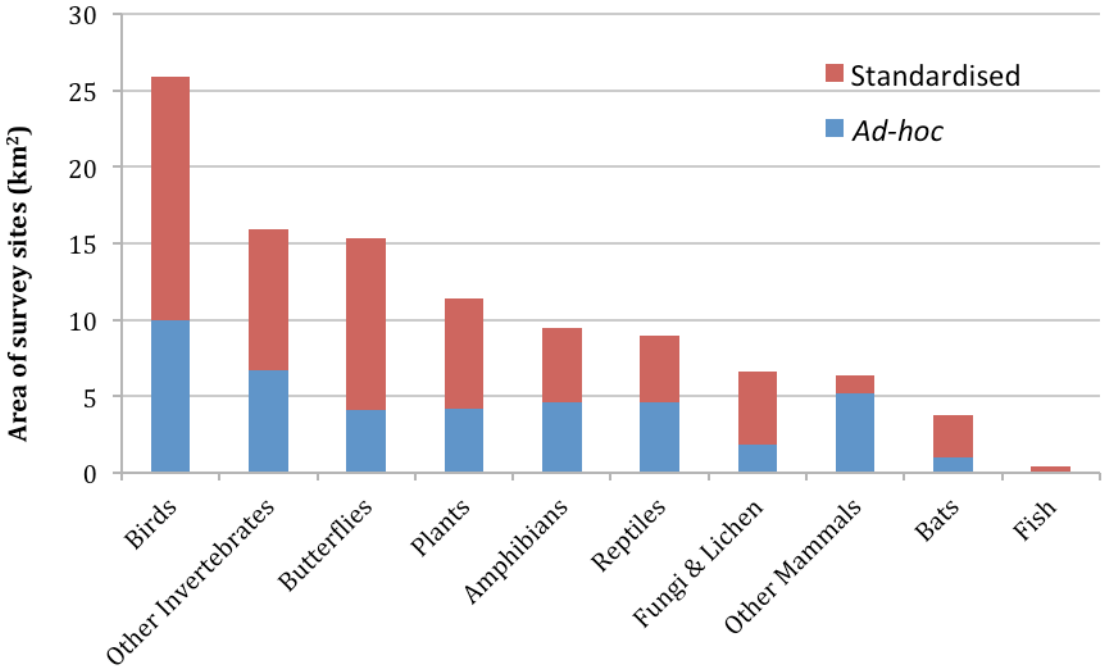


Figure 5. Variation in total area of survey sites among the species groups.

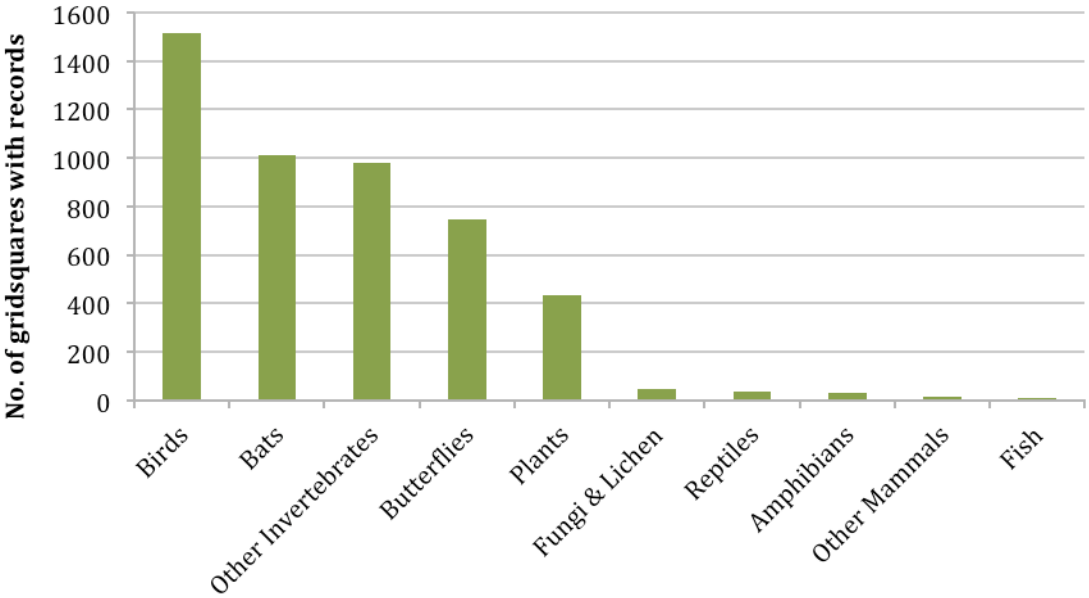


Figure 6. Variation in number of 1-km^2 grid squares containing at least one GiGL record among the species groups.

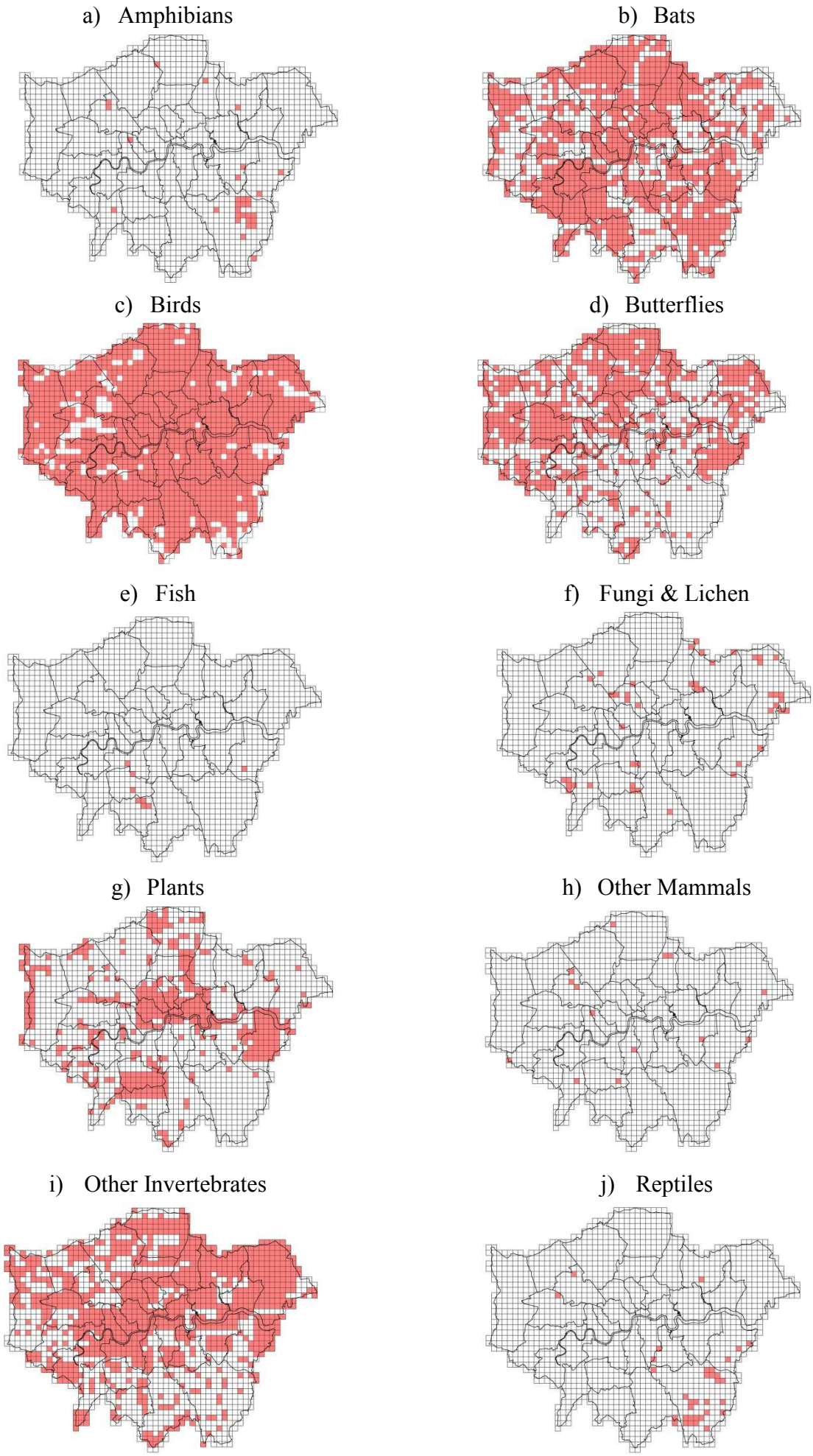


Figure 7. Spatial distribution of GiGL records in 1-km resolution by community groups in Greater London.

Spatial distribution of GiGL records varied greatly among the species groups (Fig.7). Records for Bats and Birds covered almost the entirety of Greater London. Records for Butterflies, Other Invertebrates and Plants were patchy, with clear gaps, particularly in Bromley. Records for Amphibians, Fish, Fungi & Lichen, Other Mammals, and Reptiles were extremely sparse, although records for Other Mammals were relatively well spread across Greater London. The number of monitoring surveys was also highly uneven among the Greater London boroughs (Fig.8), being most scarce in the centre borough (City of London) and most numerous in the south (Kingston upon Thames and Croydon). The spatial distribution of survey sites for each species group across Greater London was not plotted as both the area of sites and sample sizes were too small for meaningful comparison.

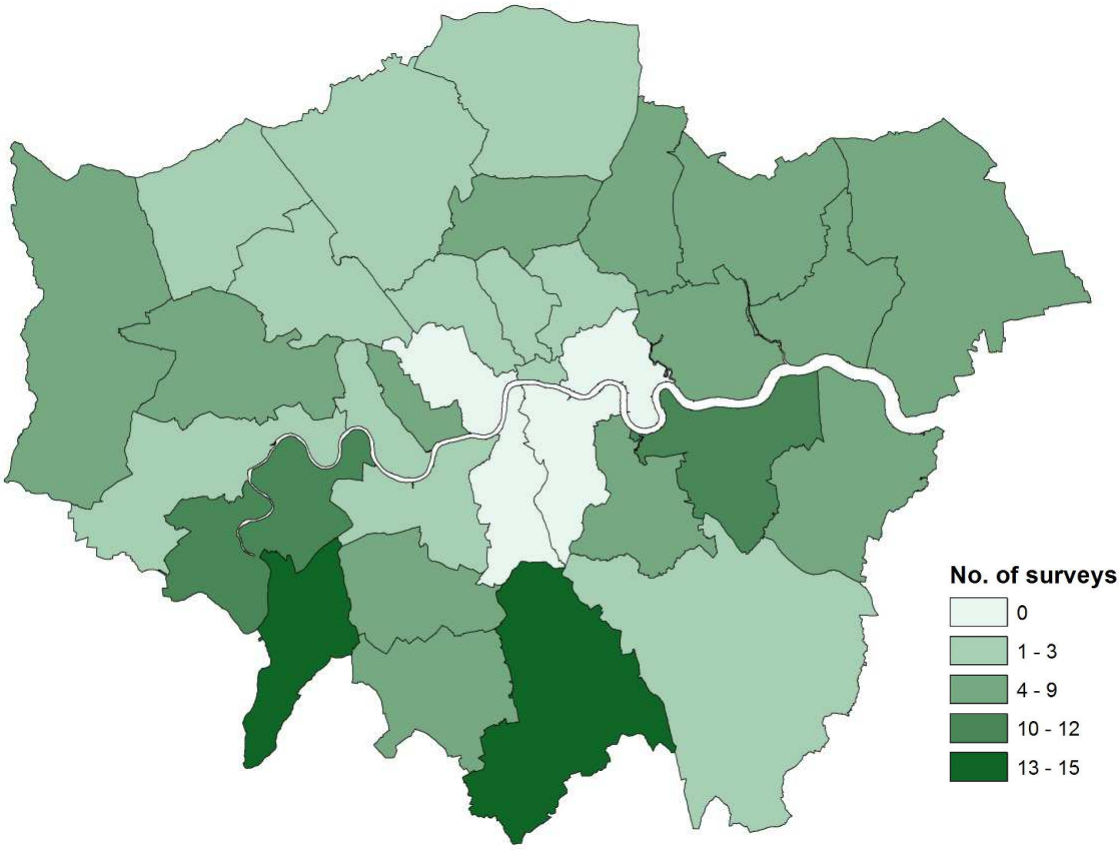


Figure 8. Variation in number of monitoring surveys conducted by community groups among the Boroughs of Greater London, based on locations of survey sites indicated in questionnaire responses (*n*=97).

4.5 Temporal coverage of CBM

Duration was provided for 91 of the 119 surveys in the questionnaire responses (Table 5). The duration for all surveys ranged from 0.16 to 120 years. 52.8% of all the surveys were new (≤ 2 years), while only 14.2% of all surveys (*n*=13) have run for 10 or more years. The longest survey duration for majority of species groups were standardised, with the exception of Birds, Plants, and Reptiles (Table 5). 97.5% of the 119 surveys indicated that they were still ongoing.

Among the ten species groups, the mean and longest duration of all monitoring surveys were skewed toward Butterflies and Birds, followed by Bats (Table 5). Mean and longest durations were shortest for Other Mammals surveys.

Table 5. Mean and longest duration of monitoring surveys (in years) for the species groups (n=91). Sample sizes for each calculation is noted. Longest survey duration for each species group is emboldened and underlined.

	All Surveys		*Ad-hoc* only			Standardised only		
	n	x̄	*n*	x̄	Longest	*n*	x̄	Longest
Amphibians	8	2.1	4	1.5	3	4	2.8	**6**
Bats	10	4.8	4	1.6	3	6	7	**15**
Birds	18	11.4	8	13.9	**45**	10	9.4	25
Butterflies	13	13.8	4	1.5	3	9	19.4	**120**
Fish	3	2.2	0	-	-	3	2.2	**4**
Fungi & Lichen	3	1.3	2	1.5	2	1	1	**3**
Other Invertebrates	13	1.4	6	1.2	3	7	1.6	**5**
Other Mammals	5	1.2	3	1.1	1.2	2	1.5	**2**
Plants	11	1.8	4	3	**5**	7	1.1	2
Reptiles	7	1.7	2	2	**3**	5	1.6	**3**

Overall, the GiGL records were skewed toward recent years, majority of data spanning 15 years between 1995-2015 (Fig.9).The drop in 2000-2015 is likely due to the lag between data collection and data sharing. Similar to the questionnaire responses, the temporal coverage of GiGL records was biased among the species groups (Fig. 10), with the highest number of 'old' records (1950-1999) for Birds, followed by Other Invertebrates, and Butterflies.

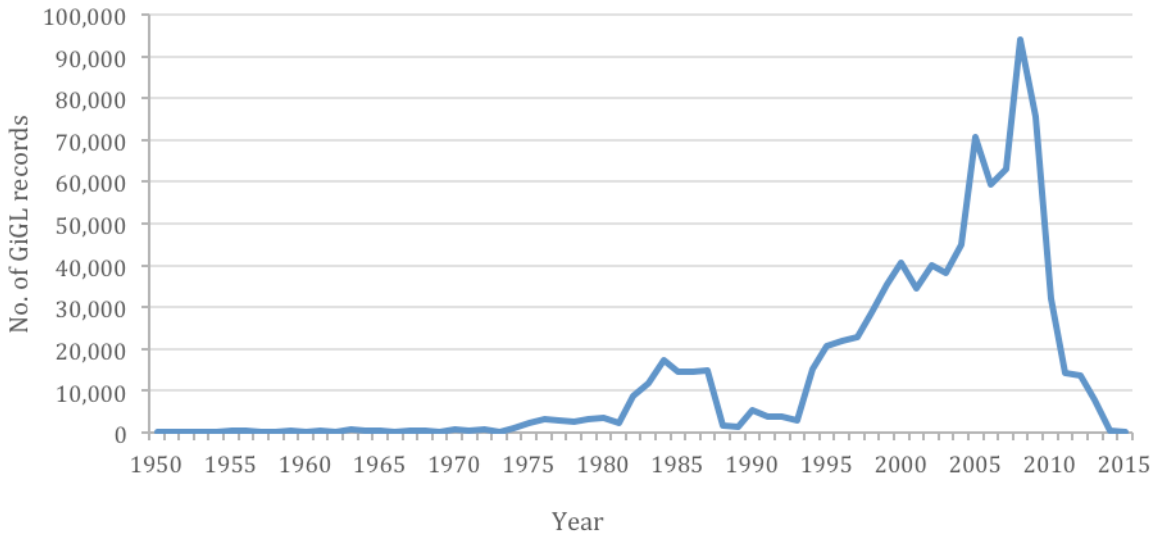


Figure 9. Number of GiGL records made by 19 community groups between 1950 to 2015.

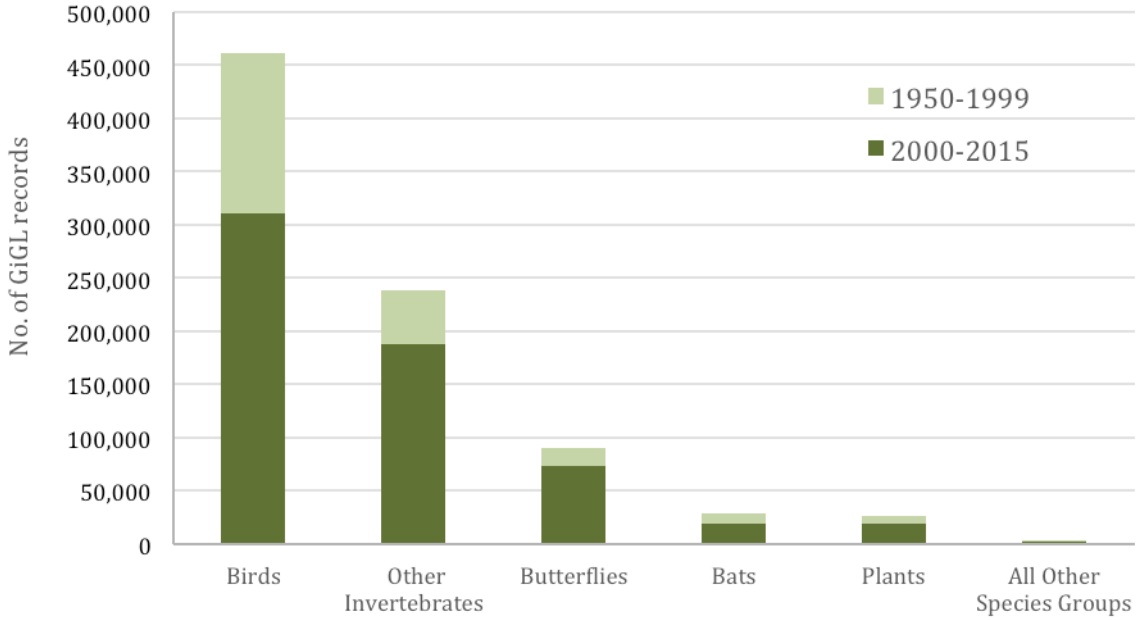


Figure 10. Variation in number of GiGL records made during 2000-2015 and 1950-1999 among the 10 species groups (*n*=849218).

4.6 Sampling method, survey organisers & data types

Questionnaire responses found a range of sampling methods employed for different species groups (Table 6). Respondents indicated that 47.7% of all standardised surveys were externally organised, with the highest for Butterflies (*n*=13) and Birds (*n*=11), and none for Amphibians, Fungi & Lichen, Other Invertebrates, Plants and Reptiles (Table 6).

Types of data collected were indicated for 80 of the 119 surveys in the questionnaire responses. Of these 80 surveys, 57.5% collected abundance data, 27.5% collected presence-only data, and 15.0% collected presence-absence data. In contrast, 85.5% of the GiGL records consist of abundance data, while the remaining 14.5% consists of presence-only data. Only 25.2% of the 119 CBM surveys collected environmental metadata, of which majority were on weather conditions. None of the GiGL records contained environmental metadata.

4.7 Data verification

Of the 119 surveys, only 37.7% had a verification process to ensure data was accurate. The most common verification process provided involved consulting an expert to check accuracy of species identification.

Table 6. Range of methods used in standardised community-based monitoring surveys for different species groups, as indicated in questionnaire responses. Number of externally organised surveys (*n*) are indicated.

Species group	Methods	External Organiser
Amphibians	▪ Refugia searches ▪ Transect walks	-
Bats	▪ Bat detector along transects by BCT	Bat Conservation Trust (BCT) (*n*=3)
Birds	▪ Transect counts following the Wetlands Birds Survey (WeBS) or the Breeding Birds Survey (BBS) by BTO	British Trust for Ornithology (BTO) (*n*=11)
Butterflies	▪ Weekly transect counts following the UK Butterfly Monitoring Scheme by BC	Butterfly Conservation (BC) (*n*=13)
Fish	▪ Trapping at set points, following the Eel Monitoring Survey by ZSL	Zoological Society of London (ZSL) (*n*=3)
Fungi & Lichen	▪ Quadrat counts	-
Other Invertebrates	▪ Light-trapping ▪ Pitfall-trapping ▪ Kick-sampling ▪ Sweep netting along transects	-
Other Mammals	▪ Transect walks	People's Trust for Endangered Species (*n*=1)
Plants	▪ Quadrat counts ▪ Transect walks	-
Reptiles	▪ Refugia searches ▪ Transect walks	-

4.8 Data sharing

Of the 47 respondents, six groups indicated that they do not share any survey data (12.8%), seven groups share data from only a fraction of their surveys (14.9%), while the remaining 34 groups share data from all their surveys (72.3%). Overall, 18 of the 119 surveys do not share data with other organisations (15.1%). Recipients of the shared data were most often the external organisers of the survey, followed by GiGL and then governmental institutions (Table 7).

Table 7. Number of surveys (*n*) which share data with other organisations in Greater London, as indicated in the questionnaires.

Recipient of data	*n*	Examples
GiGL	25	-
Other BRCs	3	National Biodiversity Network
Academic institution	1	Stafford University
Governmental institution	19	Joint Nature Conservation Committee, Croydon Council, Bexley Council
Group who organised the survey	42	Butterfly Conservation, British Trust for Ornithology
Other community groups	14	Essex Field Club, London Natural History Society

For surveys that do not share data (*n*=18), respondents provided one or more reasons along five themes (Fig.11). The most common reason was that "surveys were still ongoing". Other reasons were along the theme of constraints, or that they were unaware of organisations seeking such data.

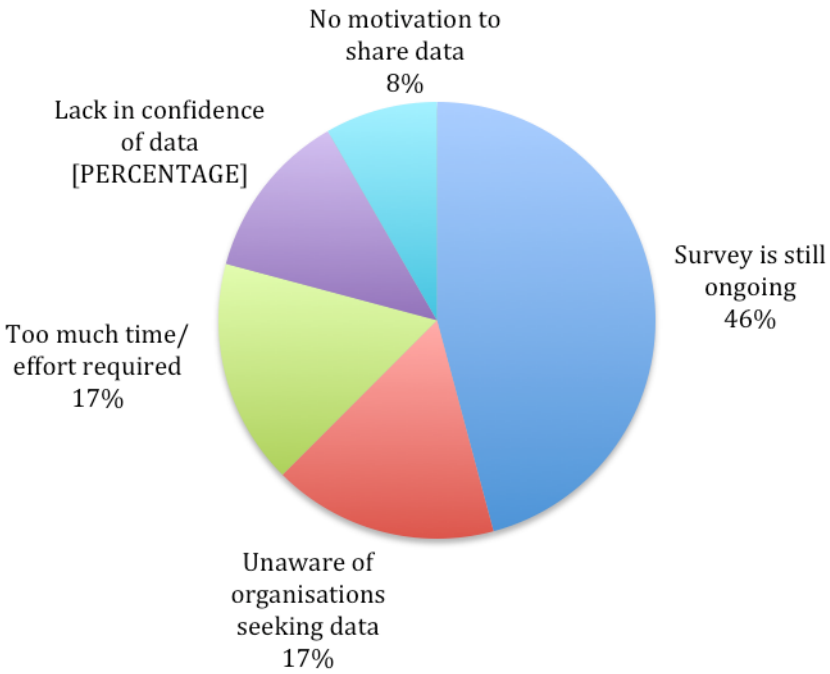


Figure 11. Themes of reasons provided by questionnaire respondents for not sharing data from their monitoring surveys (*n*=18).

4.9 Motivations for CBM

There was a highly significant relationship between top-ranked motivation for their activities to be "reasons of supporting local conservation efforts" and the conducting of CBM surveys (χ^2 test: df=3, *n*=90, χ^2 = 13.60, P=0.003). There was also a significant relationship between top motivation of local conservation and utilizing standardised protocols for surveys (χ^2 test: df=3, *n*=47, χ^2= 10.54, P=0.0145). Results are summarised in Table 8.

Table 8. Association between respondents' top motivations for their activities and whether they conduct CBM surveys or utilise standardised protocols.

Top-ranked motivation	Conduct surveys? (*n*=90)			Standardised protocol? (*n*=47)		
	Yes	No	χ^2	Yes	No	χ^2
Local conservation	33	15	13.60**	26	7	10.54*
Help scientific research	7	7		7	0	
Personal enjoyment	3	9		1	2	
Environmental awareness	4	12		1	3	
Total	47	43		35	12	

* p<0.05

** p<0.01

During the semi-structured interviews, local conservation was also cited as the most important reason for monitoring. The local groups Friends of Queens' Park and Barnet Local Group shared that they conduct conduct monitoring to "evaluate the effectiveness of their local conservation activities, such as the removal of exotic species". Chris Rose of Bexley Natural Environment Forum, also explained that they monitor Bexley's brownfield sites "to provide evidence to persuade Bexley Council to conserve them".

The county-level groups, London Natural History Society (LNHS) and Essex Field Club (EFC), cited more concern for helping scientific research, expressing enthusiasm to collect and prepare data for sharing. In contrast, local and borough-level groups cited constraints in manpower in compiling and sharing data. This may be because the interviewed county-level groups both had a larger membership and dedicated members tasked with managing the biological records. A challenge shared by all groups was aging membership. Currently, a large majority of community group members are retirees above 70 years of age, making it difficult for them to conduct surveys with physically strenuous protocols.

4.9.1 Contribution of GiGL records

The contribution of GiGL records were extremely uneven among community groups (Fig.12): vast majority were made by the London Natural History Society alone (77.2%, n=693468), followed by Essex Field Club (14.1%, n=126605), while the remaining 17 community groups made 8.7% of the records. The temporal coverage of records showed the same bias among community groups, with the London Natural History Society and Essex Field Club providing 63.2% and 28.6% of all old records in the dataset respectively. (Figure 1).

Figure 12. Variation in number of GiGL records made by 19 community groups between 2000-2015 and 1950-1999 in Greater London.

5. Discussion

For CBM to be an effective monitoring tool for Greater London, it must have representative spatial coverage, a large sample size, and temporal coverage to detect trends over time. The first major finding from this study is that these conditions are only fulfilled for three of the 10 species groups: Birds, Butterflies and Other Invertebrates are (Fig.13).

	Variable	AM	BA	BI	BF	FI	FL	OI	OM	PL	RE
	No. of surveys (Q)										
	No. of records (G)										
Space	Area of survey sites (Q)										
Space	No. of gridsquares (G)										
Space	Distribution of records (G)										
Time	Mean length survey (Q)										
Time	No. of old records (G)										

Figure 13. Traffic-light colors indicating state of variables of spatial and temporal coverage of community-based monitoring for the ten species groups inferred from data from questionnaire responses (Q) and GiGL records (G). AM: Amphibians, BA: Bats, BI: Birds, BF: Butterflies, FI: Fish, FL: Fungi & Lichen, OI: Other Invertebrates, OM:

As there is insufficient evidence that certain taxa can be effective cross-taxon surrogate for biodiversity (Andelman et al., 2000), poor representation of six of the 10 species groups precludes applications of the CBM data that require biodiversity representation. However, the good CBM datasets for Birds, Butterflies, and Other Invertebrates can still be used to achieve other aims in research and management within Greater London (Powney & Isaac, 2015). For example, CBM for these taxa

can provide data trends that can be paired with environmental information in correlational studies to examine important urban ecology questions identified by Niemelä (2014), such as the impact of demographic drivers on species within Greater London (Turner, 2003). The wide coverage and number of surveys for taxa can also be effective as surveillance against invasive invertebrate species, enabling early-warning management (Gallo & Wait, 2011). CBM can also guide conservation by serving to detect important urban habitats for endangered Butterflies, Bats and Other Invertebrates (Dickinson et al., 2010).

Contrary to previous suggestions, this study shows that several community groups employ standardised protocols (Conrad & Hilchey 2011). This finding is important as data-users have traditionally perceived CBM data collection as *ad-hoc* and unreliable (Roy et al., 2012), causing CBM to have a relatively low impact of CBM in policy and scientific publications (Conrad & Hilchey, 2011; Tulloch et al., 2013). This issue can be overcome if metadata is attached to the records, allowing users to filter the data according to their needs (Madin et al., 2007; Bird et al., 2014). However, this study finds that while community groups possess useful metadata on methods or environmental conditions and useful data types such as presence-absence data (Roy et al., 2012), these are not stored within the GiGL records.

Lastly, this study identified local conservation as the most important motivation for groups to conduct monitoring surveys and utilise standardised protocols. This finding is congruent with surveys by Davies et al. (2011) and Wolcott et al. (2008), and suggests that community groups recognise the need for robust monitoring in conservation assessments.

5.1 Future perspectives

Gaps in spatial coverage for the least represented species groups (Fish, Fungi & Lichen; and Other Mammals) need to be addressed. This might be achieved through collaborations with community groups that conduct activities in gaps areas (Gouveia et al. 2004). This study found that several externally-organised surveys with standardised protocols were undertaken for birds and butterflies. Likewise, more CBM surveys may be conducted for other taxa if standardised protocols were developed for them. However, encouraging surveys for relatively uncharismatic taxa might be challenging among community groups that prefer to monitor flagship species such as butterflies to garner support for local conservation, or if protocols are too physically strenuous for elderly volunteers (Roy et al., 2012). If monitoring of these taxa is by community groups remain low, the data might need to be complemented by professional monitoring systems in the future (Conrad & Hilchey, 2011).

As the majority of CBM surveys are short and most community groups do not hold long time-series dataset, sustaining CBM in Greater London is crucial to increase temporal coverage (Wolcott et al., 2008; Couvet et al., 2008). The reasons groups withhold monitoring data, as identified in this study, should therefore be addressed by informing groups of the value of their monitoring data toward biodiversity conservation in Greater London (Couvet et al., 2008; Dickinson et al., 2012). Modern technologies such as smartphone apps can be employed to facilitate data collection and sharing by community groups, and might also help attract younger participants (Gouveia et al., 2004; Newman et al., 2012; August et al., 2015).

Finally, while several statistical methods have been recently developed for dealing with heterogeneous CBM records without metadata, inclusion of metadata can improve the range of uses and analyses possible (Isaac et al., 2014). Metadata thus needs to be incorporated within CBM repositories in the UK (Bird et al., 2014).

5.2 Limitations

Data was captured from a maximum of three surveys per community group in order to keep the questionnaire brief. However, at least 22 respondents indicated that the group conducted more than three surveys, hence a large amount of survey information was unrecorded. Crucially, the sample may have an overrepresentation of standardised surveys if respondents deliberately prioritised them over *ad-hoc* surveys

Additionally, as questionnaires were self-assessed, responses may reflect idealised rather than actual attributes (Roy et al., 2012). To overcome this, future studies might conduct fieldwork to observe and evaluate attributes of CBM (Danielsen et al., 2005). This can provide more objective data but will result in fewer samples.

Lastly, several taxonomic groups were lumped as 'Other Invertebrates' for analysis. A dedicated investigation on CBM for individual invertebrate groups is crucial as they can provide key ecosystem services even in urban ecosystems (McFrederick & LeBuhn, 2003).

6. Conclusions

Pooling the monitoring efforts from individual community groups provides an important dataset that could not be feasibly gathered by professionals alone. Understanding the characteristics of CBM to harness its strengths and identify its uses is thus essential. This study finds that while CBM in Greater London has extreme taxonomic unevenness, it is suitable for scientific research and management concerning birds, butterflies and other invertebrates.

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Appendix 1. Online questionnaire for representatives of community groups.

1. What is the name of your group?

2. Please fill in your name and position in the group:

3. For contact purposes, please fill in your contact number and/or e-mail address

4. Please rank the following in order of relevance to your group's motivations (1 being most relevant, 4 being the least)
    a. To collect data to help science & policy
    b. For personal interest and enjoyment of participants
    c. To promote awareness of nature among the public
    d. To conserve nature in your local area

5. Please briefly describe the focus of your groups' activities.

6. What is the geographic area covered by your group?
   Please list specific names of locations. If possible, please also include GPS coordinates, grid reference, or a url link to an online map.

7. What taxonomic groups does your group cover? Please select multiple answers if necessary.

8. Does your group carry out surveys to record data?
   We define a "survey" as an activity that collects data to understand changes in biodiversity through time. Surveys can be short-term or ongoing.
   - Yes, we conduct surveys to record species data
   - No, we do not conduct surveys nor do we record data at all
   - No we do not conduct surveys, however we record data by other means

9. How many separate surveys has your group conducted within Greater London?

10. For each separate survey that your group has conducted, participated in, or organised within the last 12 months, please list the following information in the boxes below where applicable:

- Survey name;
- Focus/purpose of the survey (e.g. taxonomic groups covered);
- Organising group name;
- Time period (start and end date);
- Location

11. Please fill in the name of a survey carried out by your group in Greater London.

12. Around how many group members have participated in this survey?

13. Is the survey organised by your group?
    - Yes
    - If no, please fill in the name of the survey organizer

14. Is the survey conducted on behalf of, or paid for, by another organization?
    - If Yes, please fill in the type of organization.
    - No

15. When did this survey start? Please fill in the approximate date the survey started.

16. Is this survey ongoing?
    - Yes
    - If No, please fill in the approximate end date for the survey.

17. In which borough(s) of Greater London is the survey carried out?

18. Please list the precise names of all survey locations, and whether the entirety of the site is surveyed. If possible, please provide GPS coordinates of the sites.

19. Please tick all the habitat types are included in this survey.
    A. Grassland
    B. Woodland
    C. Marshland
    D. Gardens
    E. Water bodies
    F. Urban spaces, e.g. carparks, brownfield sites

G. Others _____

20. How often is this survey carried out?
    - Daily
    - Monthly
    - Irregularly
    - If seasonally, please fill in which seasons:

21. What taxonomic groups do you record in this survey? Please select multiple answers if necessary

22. What data about the taxa do you record? Please select all the data recorded for the survey, and fill in if not listed.
    - Presence
    - Presence and absence
    - Numbers/ Abundance
    - Biometric data/ Body measurements
    - Other:
    - Other:

23. Do you record data about the environment or habitat? (E.g. weather, pH level, nutrient levels, etc).
    - No
    - If yes, please fill in the environmental data recorded for this survey

24. Do you conduct repeats of this survey at the same locations?
    - Yes
    - No

25. What methods do you use in this survey?

    Please briefly describe how the survey's design and how this survey is carried out. If the survey method is available online, please provide a url link.

26. Do you provide training for your group's members before they conduct surveys?
    - Yes
    - No

27. Is there a data verification process to check that the collected data is accurate?

- No
- If yes, please briefly fill in the details of the verification process for this survey.

28. Are the data collected by your group shared with other groups or organisations?

- If no, go to 28a.
- If yes, go to 28b.

28a. Please tick the reasons why the data is not shared with other groups/ organisations :

- Not aware of organisations who might want the data
- No reason to do so
- Too much time / effort needed
- The data belong to the organization which paid for the survey
- The data may be used inappropriately, and so can't be shared
- Other reasons, fill in: _____

28b. Please the names of all groups/ organisations/ surveys whom you share data with.

Appendix 2. The 12 groups that contributed to the GiGL data set analysed in this study.

Community group	Scope	No. of GiGL records contributed
Cambridge & Essex Butterfly Conservation	County	7503
Barnet Local Group	County	1
Essex Field Club	County	126605
Friends of Ainslie & Larks Wood	Local	117
Friends of Littleheath Woods	Local	639
Fryent Country Park Frog	Local	24
Harrow Natural History Society	Local	30
Herts & Middlesex Butterfly Conservation	County	16314
Kingston University Biodiversity Action Group	Borough	144
London Natural History Society	County	644746
London Fungus Group	County	414
Mitcham Common Conservators	Local	20205
London Bat Group	County	26769
Woodlands Farm Trust	Locla	4080
Orpington Field Club	Borough	172
Riverfly	UK	134
Sidcup & District NHS	Borough	1164
Surrey Butterfly Conservation	County	148
West Way Trust WIldlife Garden	Local	42

Appendix 3. The 47 groups that conduct community-based monitoring surveys in Greater London discovered via the questionnaire. Groups that indicate that they currently share data with GiGL are ticked. .

Group Name	Scope	Taxonomic groups	GiGL?	Locations of specific monitoring sites
Barnet Local Group	Borough	Reptiles	✓	Mill Hill Road Old Railway
Beddington Farmlands Bird Group	Local	Birds	✓	Beddington Farmlands
Bexley Natural Environment Forum	Borough	Mammals excluding bats, reptiles, amphibians	✓	All Bexley Borough allotment sites, River Crane, River Wansunt, Thames River Wetland, Wyncham Stream
Butterfly Conservation Cambridge & Essex Branch	Borough	Butterflies	✓	Tylers Common, Lee Valley, Gunpowder Park, Waterworks, Walthamstow Marshes, Cornmill Tree park, Woodland Golf Course, Fernhills, Fairmead, Yardley Hill, Strawberry Hill
Butterfly Conservation Herts & Middlesex Branch	Borough	Butterflies	✓	Trent Park, Cranford Park, Harrow
Butterfly Conservation Surrey & SW London Branch	Borough	Butterflies	✓	Monitoring conducted in SW London, but no specific sites mentioned
Environmental Trust for Richmond	Borough	Invertebrates, fish, plants		Green Lane, Berrylands, Kingston, Stoney Sluice, Brentford, Tolworth Court Farm
Epsom & Ewell RSPB Group	Borough	Birds, butterflies, mammals excluding bats		Berrylands
Essex Field Club	Borough	All groups	✓	Monitoring conducted in Waltham Forest, Redbridge, Havering, Barking & Dagenham, but no specific sites mentioned
Friends of Dacreswood	Local	Birds, plants		Dacres Wood Nature Reserve
Friends of Foxley	Local	Amphibians, reptiles, bats, birds, butterflies, plants		Foxley Wood
Friends of Hilly Fields	Local	Bats, birds, plants		Hillyfields
Friends of King's Wood	Local	All groups		King’s Wood
Friends of Littleheath Woods	Local	Birds, butterflies, fungi, plants		Littleheath Woods
Friends of Margravine Cemetery	Local	Birds, invertebrates, plants	✓	Maragavine Cemetery

Friends of One Tree Hill	Local	Bats, birds, butterflies		One Tree Hill Park
Friends of Queen's Wood	Local	Plants		Queen's Wood
Friends of Selsdon Wood	Local	Birds, butterflies		Selsdon Wood
Friends of the River Crane Environment	Local	Invertebrates		Lower Crane Valley, downstream from Donkeywood to confluence with River Thames in Isleworth.
Friends of the Westcombe Woodlands	Local	Bats, birds, invertebrates		Westcombe Woodlands
Hertfordshire & Middlesex Bat Group	Borough	Bats	✓	Across Greater London. No specific sites mentioned.
Kent Field Club	Borough	Mammals, plants		No specific sites mentioned
Kingston Biodiversity Network	Borough	Plants		Tolwroth Court Farm, Tolworth University Sports Pitches
Kingston University Biodiversity Action Group	Borough	Amphibians, birds, invertebrates, plants, reptiles, mammals		Kingston University campus, Penrhyn rd, Knights Park/middle mill, Tolworth Court, Kingston Hill, Dorich house, Roehampton Vale, Tolworth court
Lesney Abbey Woods Conservation Volunteers	Local	Amphibians, plants		Lesnes Abbey Woods
Lewisham Biodiversity Partnership	Borough	Invertebrates, plants		Lewisham Borough
London Dragon Finder	London	Amphibians, reptiles	✓	Waterworks Nature Reserve
London Natural History Society	London	All groups	✓	Staines Moor, Banks of Colne River, Fryent Country Park, Beane Hill,
London Wildlife Trust, Hillingdon Local Group	Borough	All groups		Hillingdon Borough
London Wildlife Trust, Merton Branch	Borough	Plants, lichen	✓	Farm Bog, Wimbledon Common
Marylebone Birdwatching society	County	Birds		Hampstead Heath, Regent Parks, Rainham RSPB nature reserve, Crossness RSPB nature reserve, Rickmansworth/Stockers Lake
Mosquito Recording Scheme	UK	Invertebrates		Newham
Natures Gym Richmond	Local	Birds, butterflies, plants		Common woods, Oak Acenue nature reserve
North West Kent Countryside Partnership	Borough	Plants, mammals excluding bats		River Cray, St Paulinus Living Churchyard
Orpington Field Club	Borough	Fungi		Bromley and West Kent, but no specific monitoring sites mentioned.

Pensford Field Environment Trust	Local	Butterflies		Pensford Field
People's Trust for Endangered Species	UK	Mammals		Across Greater London. No specific monitoring sites mentioned
Richmond Park Bird Recording Group	Local	Birds		Richmond Park
Richmond Stagbeetle Group	Local	Invertebrates		Richmond Park
Sutton Nature Conservation Volunteers	Borough	Plants	✓	Cuddinton meadows, Carshalton road pastures
The Conservation Foundation	UK	Plants		
The Conservation Volunteers at Greenwich Peninsula Ecology Park	Local	All groups	✓	Greenwich Peninsular Ecology Park
The Selborne Society	Local	Invertebrates		Perivale Wood
Wild About Hampstead Heath	Local	Amphibians, reptiles	✓	Hampstead Heath
Wild Trout Trust	UK	Fish		-
Wildlife Garden at the NHM	Local	All groups		NHM Museum Garden
Wimbledon and Putney Commons Conservators	Local	All groups	✓	Plain on Wimbledon and Putney Commons and adjacent heathland patch, Bluegate pond and wooded area between Bluegate and The Plain

*Emboldened groups conduct at least one standardized monitoring survey.