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Assessing Citizen Contributions to Butterfly Monitoring in Two Large Cities

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Abstract: *Citizen science may be especially effective in urban landscapes due to the large pool of potential volunteers. However, there have been few evaluations of the contributions of citizen scientists to knowledge of biological communities in and around cities. To assess the effectiveness of citizen scientists' monitoring of species in urban areas, we compared butterfly data collected over 10 years in Chicago, Illinois (U.S.A.), and New York City, New York (U.S.A.). The dates, locations, and methods of data collection in Chicago were standardized, whereas data from New York were collected at any location at any time. For each city, we evaluated whether the number of observers, observation days (days on which observations were reported), and sampling locations were associated with the reported proportion of the estimated regional pool of butterfly species. We also compared the number of volunteers, duration of volunteer involvement, and consistency of sampling efforts at individual locations within each city over time. From 2001 to 2010, there were 73 volunteers in Chicago and 89 in New York. During this period, volunteers observed 86% and 89% of the estimated number of butterfly species present in Chicago and New York, respectively. Volunteers in New York reported a greater proportion of the estimated pool of butterfly species per year. In addition, more species were observed per volunteer and observation day in New York, largely due to the unrestricted sampling season in New York. Chicago volunteers were active for more years and monitored individual locations more consistently over time than volunteers in New York. Differences in monitoring protocol—especially length of sampling season and selection protocol for monitoring locations—influenced the relationship between species accrual and sampling effort, which suggests these factors are important in volunteer-based species-monitoring programs.*

Keywords: citizen monitors, citizen sensors, Lepidoptera, sampling effort, species accumulation, urban biodiversity, volunteer efficiency

Evaluación de Contribuciones de Ciudadanos al Monitoreo de Mariposas en Dos Ciudades Grandes

Resumen: *La ciencia ciudadana puede ser especialmente efectiva en paisajes urbanos debido a la gran disponibilidad de voluntarios potenciales. Sin embargo, existen pocas evaluaciones de las contribuciones de los científicos ciudadanos al conocimiento de las comunidades biológicas en y alrededor de las ciudades. Para evaluar la efectividad del monitoreo de especies por científicos ciudadanos en áreas urbanas, comparamos los datos de mariposas recolectados a lo largo de 10 años en Chicago, Illinois (E.U.A.) y Nueva York, Nueva York (E.U.A.). Las fechas, localidades y métodos de recolección de datos en Chicago fueron estandarizadas, mientras que los datos de Nueva York fueron recolectados en cualquier localidad en cualquier tiempo. Para cada ciudad evaluamos si el número de observadores, días de observación (días en que se registraron las observaciones) y localidades de muestreo se asociaban con la proporción reportada de las especies de mariposas regionales. También comparamos el número de voluntarios, la duración de la participación de voluntarios y la consistencia de los esfuerzos de muestreo en localidades individuales en cada ciudad. De 2001 a 2010 hubo 73 voluntarios en Chicago y 89 en Nueva York. Durante ese período, los voluntarios observaron 86% y 89% del número estimado de especies de mariposas presentes en Chicago y Nueva York, respectivamente. Voluntarios en Nueva York reportaron una mayor proporción de la riqueza estimada de especies de mariposas*

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por año. Adicionalmente, se observaron más especies por voluntario y día de observación en Nueva York, debido principalmente a la temporada de observación sin restricciones en Nueva York. Los voluntarios de Chicago fueron activos por más años y monitorearon localidades individuales más consistentemente en el tiempo que los voluntarios de Nueva York. Las diferencias en el protocolo de monitoreo – especialmente la duración de la estación de muestreo y el protocolo para la selección de localidades de monitoreo – influyeron en la relación entre el incremento de especies y el esfuerzo de muestreo, lo cual sugiere que estos factores son importantes en los programas de monitoreo de especies llevados a cabo por voluntarios.

Palabras Clave: acumulación de especies, biodiversidad urbana, eficiencia de voluntarios, esfuerzo de muestreo, lepidóptera, monitores ciudadanos, sensores ciudadanos

Introduction

As the human population in urban landscapes increases (Pickett et al. 2011), there is increasing recognition of the benefits of monitoring and conserving species in and around cities (Sanderson & Huron 2011). Given the high human population density within urban landscapes, a potentially useful strategy to detect trends in status of urban species across large spatial and temporal extents is to use data collected by citizens (Cooper et al. 2007; Devictor et al. 2010; Dickinson et al. 2010). Citizen science commonly refers to scientist-led projects that engage citizens in hypothesis-driven inquiry (Silvertown 2009). However, citizens increasingly provide unsolicited georeferenced data (often collected with ad hoc methods) on the Internet (Goodchild 2007; Wiersma 2010). Although data collected with either standardized or unstandardized methods have the potential to provide valuable information about plant and animal communities in human-altered ecosystems, inferences may be limited if the data are biased toward certain species (Lepczyk 2005), if the majority of species present in the ecosystem are not detected (Couvet et al. 2008), or if sampling effort is inconsistent over time (Magurran et al. 2010). An appraisal of different approaches to collection of data by citizen scientists might inform and maximize the efficiency of data-collection efforts in urban areas.

Many monitoring programs seek to document the presence and trends in abundance of species in an area, but methods differ considerably. For example, eBird, a project developed by the Cornell Laboratory of Ornithology and the National Audubon Society, compiles observations of birds made by citizen scientists at any location and time (Sullivan et al. 2009). In contrast, the North American Breeding Bird Survey uses a standardized method to collect data along established roadside routes at particular times (Robbins et al. 1986). In both programs, data are collected by a large number of people at a large number of locations. Despite the differences in sampling methods, the quality of data and the efficiency of data collection for the 2 programs are similar (Munson et al. 2010). Such similarities may not result from more localized citizen–science efforts.

Butterflies are one of the taxonomic groups most commonly monitored by citizens (Schmeller et al. 2009), and several European programs involve citizens in standardized monitoring of butterfly assemblages (e.g., United Kingdom, Butterfly Monitoring Scheme; France, Butterfly Garden Observatory) (Pollard & Yates 1994; van Swaay et al. 2008). In addition, a number of citizen–science programs in the United States, Mexico, and Canada focus on migration and trends in abundance of *Danaus plexippus* (Monarch) butterflies (e.g., Journey North, Monarch Larva Monitoring Project, Monarch Watch) (Oberhauser & Prysby 2008; Howard & Davis 2009). However, there have been relatively few evaluations of citizen contributions to monitoring entire butterfly assemblages in North America, especially in urban landscapes, where citizen science might be most effective for detecting species trends (Cooper et al. 2007) and most likely to promote conservation (Sanderson & Huron 2011). We use the term *urban* to refer to areas with high human population density, where the majority of the land cover is built structures (Pickett et al. 2011).

We assessed butterfly data collected by citizens over a 10-year period in Chicago and New York City (U.S.A.). The data were collected with different methods. Data from Chicago were collected under a strict monitoring protocol, whereas data from New York were collected at any location at any time. We evaluated how the number of observers, observation days (days on which an observation was reported), and sampling locations affected the reported proportion of butterfly species estimated to occur in each city. In addition, we compared the number of volunteers and duration of their involvement (in years) for each city and the consistency of sampling efforts at specific locations within each city. Our goals were to assess the effectiveness of each program's volunteer efforts at documenting most butterfly species in the area and to provide guidelines for improving collection of species-presence data by citizen scientists in urban areas.

Methods

Data Sets

In Chicago, butterfly data were collected by members of the Illinois Butterfly Monitoring Network. Volunteers monitor specific locations by walking a minimum of 6 Pollard transects (Pollard 1977) between 1 June and 7

August each year. To monitor each transect, volunteers walk at a slow, uniform pace and record all species observed within a 6-m radius of the observer and the total monitoring time (Panzer et al. 2004). All transects are in protected areas managed for conservation purposes. In contrast, the New York data were compiled from individual reports submitted by butterfly enthusiasts visiting any location at any time. The majority of reports were submitted by local naturalists and active members of the New York City Butterfly Club and the New York Chapter of the North American Butterfly Association. We gathered records for the New York metropolitan area (between 2001 and 2010) from the association's digital archives (NABA 2011*a*). Prior to inclusion in the database, records must be deemed credible by a local expert.

For both cities, we included only butterflies detected within a 56-km radius (9850 km^2 area) of the urban center from 2001 to 2010. This distance encompasses all monitoring locations in Cook County, Illinois, which includes the city of Chicago. This same distance included observations from all 5 counties (boroughs) within New York City and parts of several heavily populated surrounding counties (Monmouth, Middlesex, Union, Essex, Hudson, Passaic, Rockland, Westchester, Nassau, and Suffolk and Bergen in New Jersey). Although technically these boundaries exceed the city limits of both cities, we refer to the metropolitan areas as Chicago and New York. In each city, every species record was attributed to a particular observer. If multiple observers were listed for a species record, we only counted the observer who had submitted the greatest number of butterfly records (hereafter primary observer). We removed all records that could not be attributed to a specific location. Common names of species follow the North American Butterfly Association (NABA 2011*b*); scientific names follow Pelham (2011). We screened both data sets for spurious records (e.g., rare species reported from unlikely locations or at unlikely times) (Supporting Information) and did not include those records in our analyses. We defined rare species as those constituting $<2\%$ of all records for each city.

Assessment of Monitoring Efficiency, Consistency, and Bias

For each city, we compared the average number of species reported by one observer on a single day. To assess the ability of each city's monitoring efforts to provide information about butterfly species on an annual basis, we used a paired t test to compare the proportion of the estimated pool of butterfly species reported yearly in each city. A paired t test was used because spatially extensive stochastic weather events might similarly affect butterfly species in both cities.

Sampling of living organisms is rarely exhaustive, and observed species richness usually underestimates true species richness (Colwell & Coddington 1994). To enable comparison of the degree to which each monitoring program detects most species in its geographic area, we used several methods to estimate the total number of species expected: range maps (Brock & Kaufman 2003), species lists provided by local experts, and the $Chao_2$ estimator of species richness (Chao 2004). We evaluated how the addition of primary observers, observation days, and sampling locations in each city contributed to the cumulative number of butterfly species reported over the 10 years. Because we expected the number of butterfly species to differ between the cities, we plotted the proportion of the estimated total number of butterfly species for all accumulation curves. We created rank-incidence diagrams for each city to compare the relative number of unique records (i.e., incidences) for all species. We used PRIMER (version 6.1.13) (Clarke & Gorley 2006) to create accumulation curves with 999 permutations of the species matrix and SigmaPlot (version 11.0) (SystatSoftware 2008) to calculate comparative statistics.

We compared the number of volunteers and the duration of their involvement (number of years reporting data, not necessarily consecutively) in each city. We also examined consistency in the number of observation days at locations with ≥ 5 years of data from 2001 to 2010. For each of these locations, we calculated the number of observation days each year. We then used a Mann–Whitney test to compare the standard deviation of number of observation days at each of the Chicago sites with those at each of the New York sites over time.

Post Hoc Analyses

The analyses described above indicated that a greater proportion of the estimated pool of butterfly species was reported in New York than in Chicago. To investigate potential causes of this result, we modified the New York data set so that it would more closely resemble the Chicago data set. We adjusted the observation period for New York so that it would be consistent with the observation period for Chicago; thus, we considered only New York records between 1 June and 7 August. We included only records from the 56 locations with the greatest number of reported visits in New York (same number of sampling locations in Chicago). To evaluate the influence of duration of sampling season versus number of sampling locations on the proportion of observed species, we used a Wilcoxon rank-signs test to compare the proportion of the estimated pool of butterfly species observed each year among the following four sets of data: all New York records, New York records from 1 June through 7 August, New York records from 56 sites, and New York records from 56 sites from 1 June through 7 August. We also used Spearman rank correlations to determine whether removal of these data affected identification of temporal trends in the proportion of observed species.

Table 1. Summary statistics from citizen-based butterfly-monitoring efforts in Chicago and New York City.[a]

Measure	*Chicago*	*New York*	*New York reduced*[b]
Number of primary observers[c]	73	89	44
Number of observation days	2240	1939	547
Number of locations sampled	56	274	56
Number of months per year in which butterflies were observed	3	12	3
Number of butterfly records	101,533	118,005	42,614
Number of butterfly species recorded	89	108	95
Number of butterfly species estimated to occur in the city on the basis of range maps[d]	103	121	121
Number of butterfly species estimated to occur in the city on the basis of $Chao_2$ estimate (SD)	97 (7.5)	112 (3.9)	106 (10.3)
Proportion of regional pool of butterfly species that were observed, estimated on the basis of range maps (and $Chao_2$ estimates in parentheses)	0.86 (0.92)	0.89 (0.96)	0.79 (0.85)

[a] *Data compiled from reports submitted from 2001 to 2010.*
[b] *Sampling period and number of locations were reduced to match those of the Chicago data set.*
[c] *When multiple observers were listed for a single observation day, the observer with the most number of observations was counted as the primary observer.*
[d] *Brock and Kaufman (2003).*

Results

Range maps showed the potential presence of 103 species in Chicago and 121 species in New York. These numbers were similar to $Chao_2$ estimates (97 and 112 species, respectively) and species lists compiled by local experts (106 species in northern Illinois [Panzer et al. 2004]; 120 species in an 80-km radius of New York [Zirlin & Ingraham 1997]). Volunteers reported 89 species in Chicago and 108 species in New York from 2001 to 2010 (Supporting Information), or 0.86 and 0.89 of the respective number of species estimated on the basis of range maps (0.92 and 0.96 on the basis of $Chao_2$ estimates) (Table 1). The 2 data sets shared 74 species and 7 of the 10 species with the greatest number of records.

On average in a single day, Chicago volunteers reported a greater number of species (median = 5, range = 1–26) than New York volunteers (median = 4, range = 1–40) (Mann–Whitney $U = 390{,}4813.5$, $p < 0.001$). However, New York volunteers consistently reported a greater proportion of the estimated pool of species each year than Chicago volunteers ($\text{mean}_{\text{NewYork}} = 0.71$, $\text{mean}_{\text{Chicago}} = 0.60$; $t = 3.29$, df = 9, $p < 0.01$) (Fig. 1). Over 10 years, the increase in cumulative number of reported species as the number of volunteers and observation days increased was more rapid in New York than in Chicago (Figs. 2a & 2b). The cumulative number of reported species increased more rapidly in Chicago than in New York as the number of new locations increased (Fig. 2c). In 194 different locations, New York volunteers reported the same proportion of the estimated pool of species that Chicago volunteers reported in 56 locations. There were relatively more reports of rare species in New York compared with Chicago (Fig. 3).

The number of volunteers and observation days was similar among cities, but the number of observation locations and sampling period differed (Table 1). Although there were more volunteers in New York than Chicago over the 10-year period, there were significantly more volunteers in Chicago than New York on a yearly basis ($t = -2.96$, df = 9, $p = 0.02$). This was because Chicago volunteers reported observations for more years (median = 2, range = 1–10) than New York volunteers (median = 1, range = 1–10) (Mann–Whitney $U = 2466.5$,

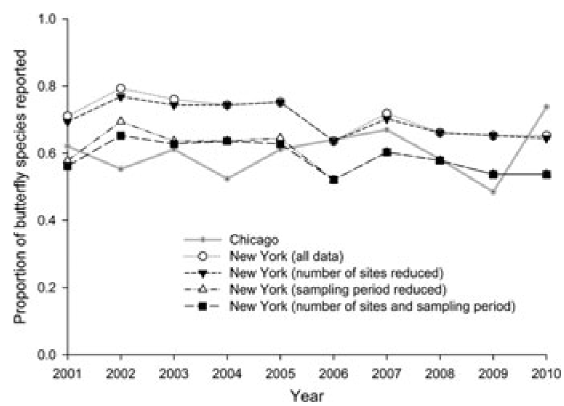

Figure 1. Proportion of regional pool of butterfly species (estimated on the basis of range maps) reported each year by volunteers in New York City and Chicago. The New York data set was modified to more closely resemble the Chicago data set, and these modifications are shown separately on the graph (number of sites reduced or length of sampling period reduced).

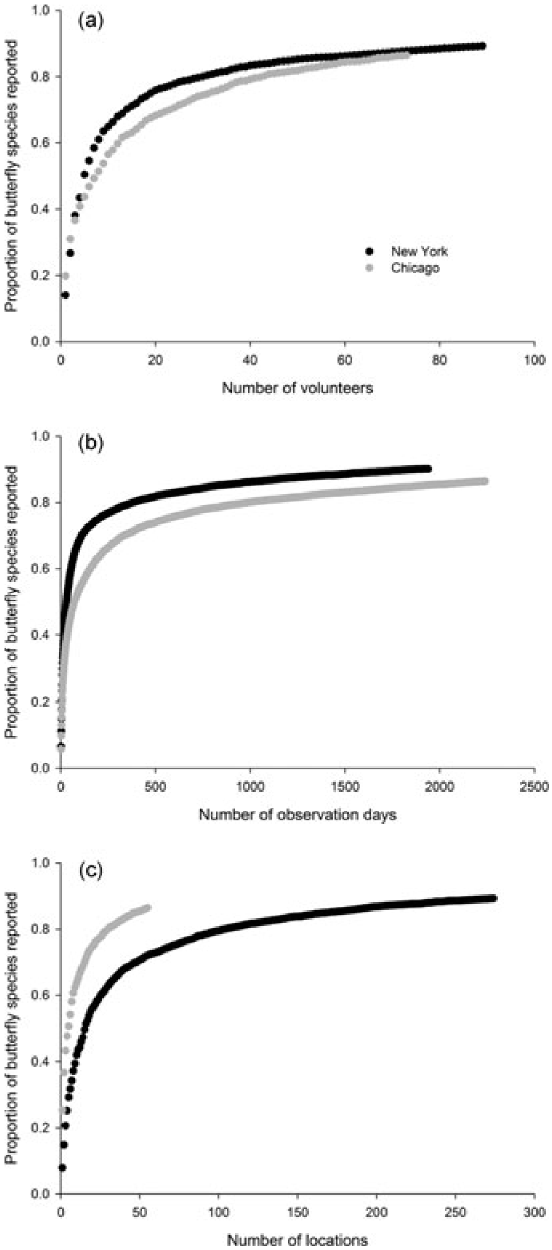

Figure 2. Cumulative proportion of the regional pool of butterfly species (estimated on the basis of range maps) reported in Chicago and New York from 2001 to 2010 on the basis of sampling effort: (a) number of volunteers, (b) number of observation days, and (c) number of locations.

$p < 0.01$). Butterfly observations in New York came from many more locations ($n = 274$) than Chicago ($n = 56$).

A similar number of sites were monitored fairly consistently (for 5 or more years) from 2001 to 2010 in Chicago (31) and New York (33). However, there was more variation in effort (as measured by the standard deviation of observation days per year at each site) in New York

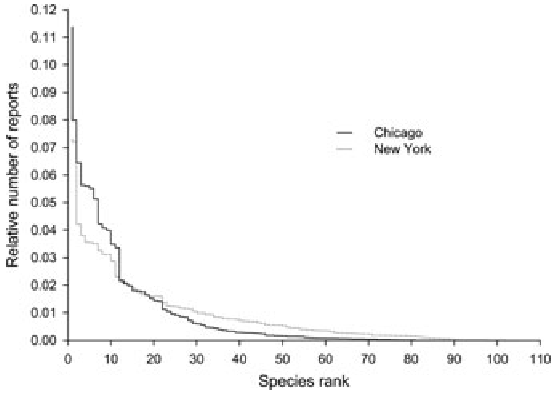

Figure 3. Proportion of records for common to rare species reported in Chicago and New York from 2001 to 2010. Each species was ranked on the basis of the number of unique records; higher ranks denote rarer species.

compared with Chicago (Mann–Whitney $U = 366.5$, $p = 0.05$).

When New York data were reduced to the same period and number of locations as Chicago, 95 butterfly species (0.79 of total on the basis of range maps, 0.88 on the basis of the $Chao_2$ estimator) were reported over 10 years. Overall, temporal restrictions and reduction of the number of sites decreased the number of species in the New York data set by 11 and 2, respectively. On a yearly basis, reducing the New York data set also resulted in fewer species observed each year. In comparisons between all pairs of New York data sets, reducing the length of the sampling season had a larger influence than reducing the number of sampling locations (Fig. 1). Wilcoxon signed-rank tests indicated significant differences between 4 of the 6 pairs ($W = -55.0$, $p < 0.01$). Nevertheless, the number of species reported each year was highly correlated among all 4 data sets (Spearman's $r = 0.94$–0.99, $p < 0.001$ for all pairings). Once both dates and sites were removed, the New York data set did not differ significantly from the Chicago data set in the proportion of butterfly species reported per year ($t = -0.50$, df $= 9$, $p = 0.63$).

Discussion

Citizen science is becoming more prevalent (Devictor et al. 2010; Dickinson et al. 2010) and may be especially effective for detecting species in urban areas because of the large number of potential volunteers. However, there is little guidance available for those who wish to initiate a new citizen–science program or modify an existing one. Butterfly monitoring in Chicago was conducted with a standardized protocol that required reporting of all observed species, whereas the monitoring in New York involved voluntary reporting of any species at any time and location. Despite these differences and differences in geographic location, habitats, and human population of the cities (e.g., >18 million people live in the New York metropolitan area compared with <10 million in the Chicago metropolitan area), we found some general similarities in the monitoring efforts. Each city had a similar number of volunteers and similar observer effort from 2001 to 2010 (Table 1). Each city also had a similar number of sites that were monitored fairly consistently over the 10 years. Moreover, volunteers in each city documented 50–80% of butterfly species in the estimated regional pool annually (Fig. 1).

In New York, the number of reported butterfly species increased more rapidly than in Chicago as the number of volunteers and observation days increased (Figs. 2a & 2b). This may have been because sampling over more months increased the likelihood of observing species that are active in spring and autumn. Consistent with this assumption, we found that restricting the sampling period decreased the proportion of observed species per year much more than reducing the number of sampling locations. Depending on the phenology of butterflies in the region, a longer seasonal sampling period may be necessary if the goal is to record all species. However, the proportion of observed species per year was correlated for both the full and temporally restricted New York data, which suggests that a shorter sampling season may be sufficient if the primary goal is to document temporal trends in species richness. Similarly, Roy et al. (2007) found reductions in sampling period to have little influence on temporal trends in abundance for 20 widespread butterfly species in Europe.

As the number of sampling locations increased, the proportion of butterflies reported increased more rapidly in Chicago than in New York (Fig. 2c). This may be because Chicago sites were visited more consistently than New York sites. In addition, the Chicago sites were intentionally established in high-quality habitat, whereas the New York data included reports from gardens, roadsides, and other potentially less species-rich locations. On the one hand, deliberate inclusion of sites with a gradient of habitat quality is necessary if the goal is to evaluate changes in species communities across a landscape. On the other hand, sampling sites with lower species richness may be of less interest to some volunteers (McCaffrey 2005) and may be less effective if the goal is to document the majority of species in the region.

Although individual New York volunteers chose where to observe butterflies, 33 sites were still monitored fairly consistently over 10 years. This reflects the tendency of butterfly enthusiasts to visit repeatedly sites where they will be most likely to observe many species. Nevertheless, there was significantly greater variation in observer effort at those sites than at the 31 consistently monitored sites in Chicago. Other researchers have found citizen–science programs that use less uniform protocols to result in more variable data (Munson et al. 2010). In contrast, the Illinois Butterfly Monitoring Network manages the Chicago area program and encourages volunteers to collect data at least 6 times per year. Standardized methods are more likely than ad hoc methods to detect trends. For instance, data collected by volunteers in Chicago documented irruptions of *Pyrisitia lisa* (little yellow) in 2008 and 2010 and *Vanessa cardui* (painted lady) in 2003 (D. Taron, unpublished data).

The 2 butterfly-monitoring networks we studied operate under very different systems of organizational governance (Conrad & Hilchey 2011). The New York effort follows a bottom-up model in which a very loose affiliation of citizen scientists collect and report data with no defined data-collection protocol. In contrast, the Illinois effort fits more closely into a more collaborative model of governance, whereby governmental agencies, nonprofit organizations, and individual volunteers actively work together to continue and expand standardized monitoring. In Chicago, volunteers were actively recruited each year and recognized at annual gatherings. In contrast, data collection in New York was generally not considered part of a cohesive effort. Social interaction is an important driver of consistent volunteer involvement (Bell et al. 2008), and retention of volunteers may increase accuracy of species identification and the ability to assess data quality. For instance, it has been suggested that error and bias may be removed from citizen–science data sets by removing the first year of a volunteer's reports (during which there may be a learning curve) (Dickinson et al. 2010).

There were relatively more reports of rare species in the New York data set (Fig. 3). It is possible that this result is an artifact of the data-collection process. If reporting all observed species is not mandated, volunteers may not report species in proportion to their abundance. For instance, *Pieris rapae* (cabbage white) was the most commonly reported butterfly in both cities (11.4% of records in Chicago and 7.3% of records in New York). However, a study conducted with standardized sampling protocols in New York found 33% of records from city parks were of *P. rapae* (Giuliano et al. 2004), which suggests that reports of fewer *P. rapae* in New York by volunteers may be due to failure to report this common species.

Munson et al. (2010) found that inferences regarding bird population trends made on the basis of data collected for the Breeding Bird Survey and eBird data were similar. This is consistent with our finding that, although protocols differed between Chicago and New York, there were several similarities in the results. Regardless of protocol, volunteers typically reported 4–5 butterfly species per report day. Furthermore, for both cities, a base of 45 volunteers identified from 80% (on the basis of range maps) to 85% (on the basis of $Chao_2$ estimates) of the total species over 10 years. Thus, 45 volunteers might be the minimum number of volunteers needed to detect the majority of species in metropolitan areas. Clearly, however, urban areas with more butterfly species or a greater proportion of cryptic species (e.g., southwestern United States, the tropics) may require more volunteers and sampling effort per unit area.

We propose that an undirected approach to data collection, such as that applied in New York, may result in more rapid and efficient detection of species, whereas a standardized protocol, such as that applied in Chicago, may result in more consistent collection of data over time. Although both approaches have merit, each may be suitable for different goals. If the primary goal is to assess change over time, we suggest that trained volunteers consistently monitor a relatively small number of sites. Alternately, if a program has a limited number of volunteers and the primary goal is to document rare species, we think it may be useful to encourage multiple volunteers to monitor sites with high species richness. For example, reports of rare species were often validated by multiple volunteers in New York, confirming potentially questionable observations.

Citizen-science projects exist for a variety of reasons including scientific inquiry, education, and increased community involvement in conservation. As the number of citizen-science programs increases, the efficacy of different citizen-science protocols can be assessed. We believe specific objectives should be established for volunteer-based species-monitoring programs, as is increasingly recommended for long-term monitoring in general (Lindenmayer & Likens 2009). Clearly articulated objectives will allow managers of citizen-science programs to optimize the data-collection efforts of volunteers.

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Supporting Information

A list of all butterfly species reported to the monitoring efforts in New York and Chicago is available online (Appendix S1). The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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