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Testing a butterfly commonness hypothesis with data assembled by a citizen science program "Tokyo Butterfly Monitoring"

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Abstract
We tested a hypothesis regarding species commonness using a database compiled by a citizen science program called "Tokyo Butterfly Monitoring." The data used were more than 34,000 butterfly records, which were cleansed through expert check after posted by monitoring participants from 2009 to 2017. We hypothesized that butterfly species with multiple annual reproductive cycles and food plants common in city environments are more common and would have more monitoring reports. The generalized linear mixed model (GLMM) analysis revealed significant effects of including "cultivated plants" in the larval food menu and "multivoltinism" on the number of individual species reported, which was compatible with the hypothesis. The species with the most records (12% of all records among 90 species) was *Zizeeria maha*, which reproduces 5–6 times annually and relies on *Oxalis corniculata*, a small weed common in urban open spaces. *Argyreus hyperbius*, a southern species that was very rare before the 1990s, ranked third in the current data. Its major host plant is a common garden plant, the pansy, which grows in most gardens and green spaces. The data collected by the monitoring program appear to represent the status of the butterfly community in Tokyo, a megacity subjected to rapid environmental changes.

KEYWORDS
butterfly, commonness, host plant, megacity, monitoring

1 | INTRODUCTION

Biodiversity-conservation-oriented citizen science has grown rapidly over the past decade (McKinley et al., 2017), probably because the conservation of biodiversity has become an important social issue under the international framework of the Convention on Biological Diversity. In contrast to the climate change policies related to the Framework Convention on Climate Change, where expert scientists play a crucial role in almost all scientific processes, from data collection and analysis to scientific prediction (Intergovernmental Panel on Climate Change [IPCC], 2014), biodiversity policies at regional to international scales are likely to be profoundly dependent on citizen science. Internationally, many skilled amateur scientists and the public contribute to monitoring biodiversity in various ways (BirdLife International, 2018; International Union for Conservation of Nature [IUCN], 2019; World Wildlife Fund [WWF], 2018). The data collected are compiled in documents such as the "Global Biodiversity Outlook," which provides a scientific basis for international policies regarding the framework of the Convention on Biological Diversity (Secretariat of Convention on Biological Diversity [CBD], 2014).

Another important driver of the recent growth of biodiversity citizen science may be the spectacular development of information technology and data engineering, which have provided new ways to contribute to, manage, analyze and engage with scientific data (Bonney et al., 2009; Sullivan et al., 2017; Wei, Lee, & Wen, 2016).

Biodiversity citizen science is growing rapidly in North America and Europe (McKinley et al., 2017; Sullivan et al., 2017). Although public involvement in biodiversity monitoring is not so active in Japan, concern regarding biodiversity as citizen science has been growing steadily (Kobori et al., 2016). The citizen science program "Tokyo Butterfly Monitoring," in which citizen volunteers report the occurrence of individual butterfly species that they observe anywhere in Tokyo, is a representative participatory monitoring program in Japan (Kobori et al., 2016).

Butterflies are distributed widely in various habitats and are familiar to people, including urban residents. They are also expected to respond rapidly to environmental changes because of their short lifecycles and relatively high mobility. Butterfly species distributions and assemblages have been reported to be changing rapidly in various climate zones (Forister et al., 2010; Hickling, Roy, Hill, Fox, & Thomas, 2006; Molina-Martínez et al., 2016; Parmesan, 2006; Wilson et al., 2005; Wilson, Gutiérrez, Gutiérrez, & Monserrat, 2007). The butterfly fauna of Tokyo is no exception because records and local checklists of amateur scientists suggest rapid changes in the butterfly community, including some local extinctions during the last quarter of the 20th century and first decade of the 21st century (Maezumi, Suda, Kadoya, & Washitani, 2010).

Because of the tremendous heat production resulting from various human activities and the massive clusters of high buildings blocking ventilation, the urban climate of a megacity is far warmer than the average global warming that our earth is facing (Peng et al., 2012; Rizwan, Dennis, & Liu, 2008). Simultaneously, industrial and residential development has caused various environmental changes related to habitat loss and fragmentation (Aronson et al., 2017; Grimm et al., 2008). The massive introduction of exotic garden plants and the invasion of alien weeds result in rapid changes in the abundance and distribution of butterfly species, including local extinctions (Maezumi et al., 2010; Ramírez-Restrepo & MacGregor-Fors, 2017).

For precise evaluation of the rapidly changing butterfly community of a megacity, larger-scale participatory monitoring is likely to be effective. This is one of the purposes of the citizen science program "Tokyo Butterfly Monitoring," co-organized and comanaged by a regional consumer co-operative and scientists in conservation ecology and data engineering. Like many other citizen science programs, the program was designed to benefit both science and society (Hecker et al., 2018), as well as the participants personally.

Major social purpose of the program is to compile baseline data on the current status of the butterfly community of Tokyo under rapid anthropogenic environmental changes to provide a database available to everyone including future citizens and scientists. The feeling of contribution to science and society through own data collection is the main incentive of participants of the program. Other merits for individual participants, which we can grasp from the opinions and comments expressed in the information exchange meetings and at the end pages of "*Nature Guide for 'Tokyo Butterfly Monitoring'*" published electrically and in a printed form (Washitani & Kitsuregawa, 2016), contain the satisfaction on enhanced own skills on butterfly identification. A vast amount of data accumulated may be useful in hypothesis or model testing requiring massive data.

This study is focused on the scientific value of the citizen science program. One indicator of scientific value is the contribution to scientific discovery through peer-reviewed papers. Using this criterion, "eBird" is remarkable in its scientific achievement, as indicated by more than 100 peer-reviewed papers based on its data (Sullivan et al., 2014). Another criterion is scientific findings available for hypothesis testing, which can involve relatively small databases, such as the one compiled by "Tokyo Butterfly Monitoring". Hypothesis testing is among the essential activities in science from the age of Galileo until now, while currently the word "model" is preferentially used, which include those constructed after data have been derived (Glass & Hall, 2008) and contributing to scientific discovery or finding.

To evaluate the scientific value of the program, we tested the "commonness hypothesis," which holds that the abundance or commonness of individual butterfly species and, thus, the reported number for the individual species is dependent on the annual reproductive frequency and commonness of food plants (Hardy & Dennis, 1999; Maezumi et al., 2010; Shreeve, Dennis, Roy, & Moss, 2001). As well as reproductive frequency, food availability is assumed to profoundly affect the population growth rate of each species through survival and reproductive outputs of individuals cumulatively should influence the population size of each species.

2 | METHODS

2.1 | Data collection and compilation

The citizen science program "Tokyo Butterfly Monitoring" is Internet-based participatory monitoring operated jointly by conservation ecologists and data engineers (the authors of this paper), and a regional consumer co-operative, "Pal-system Tokyo", which is in charge of recruiting volunteer monitors (participants) and providing necessary services, such as training events and information exchange meetings. The participants post butterfly photographs via the Internet as the main data on when and where they observed the butterflies.

The program uses a data-cleansing process in which butterfly experts identify the species in the posted photographs to guarantee identification accuracy. Then the photographs with spatiotemporal data are compiled in a database, and the participants who posted the data can check the correct species identification through the Internet. This assisted identification process works well because the proportion of correct original data increased steadily to approximately 95% within 5 years of the start of the project (Yasukawa & Kitsuregawa, 2016).

More than 500 participants collected 40,000 records of 90 butterfly species between 2009 and 2017 and these data are available to everyone through a data-sharing platform (http://butterfly.diasjp.net).

The spatial distribution and taxonomic(family)composition of the data used were given in Tables 1 and 2. The data from wards area (44.5%) and those from nonmountainous nonward area (54.3%) were relatively comparable, although those from mountainous area (1.2%) were far less than expected from the area coverage (18.6%), probably due to difficulty for participants to access most of mountainous area. Percent records were not so greatly different among families with the largest share for Nymphalidae (30.7%) and smallest share for Hesperiidae (10.8%), which are likely to reflect the relative species number for the family, and enough cover the butterfly fauna of current Tokyo, experienced butterfly specialists are expecting (S. Suda, personal communication, February 27, 2020). Yearly and seasonal patterns of the reported data are represented in Figure 1a,b. There is considerable yearly difference of reported number, with the maximum number (5,376 in 2013) approximately double the minimum number (2,669 in 2017). The pattern of monthly number of reports pooled for 9 years showed two peaks in early summer and fall, which is enough understandable as butterfly phenology under a warm temperate climate.

The commonness hypothesis we tested with the reported number of individual species is thought to be robust against spatial, taxonomic and temporal biases of these degrees, because basic species biology is thought to

TABLE 1 Number and percentage of reports for each family

Family	Number (%)
Papilionidae	5,233 (15.2)
Pieridae	6,889 (20.0)
Lycaenidae	8,015 (23.3)
Nymphalidae	10,575 (30.7)
Hesperiidae	3,703 (10.8)
Total	34,415 (100.0)

Note: Data were pooled for 9 years.

TABLE 2 Area coverage and number with percentage of occurrence reports observed for "wards" area (23 wards), nonwards "nonmountainous" area (cities, towns and villages in the mainland of Tokyo except for Hinohara Village and Okutama Town), or "mountainous" area (Hinohara Village and Okutama Town) of Tokyo

Area	km^2 (%)	Number (%)
Wards	618.97 (34.8)	15,299 (44.5)
Nonwards	828.88 (46.6)	18,689 (54.3)
Nonmountainous		
Mountainous	330.94 (18.6)	423 (1.2)
Total		34,411 (100.0)

Note: Reports without mention of the administrative district where the observations were taken place are excluded.

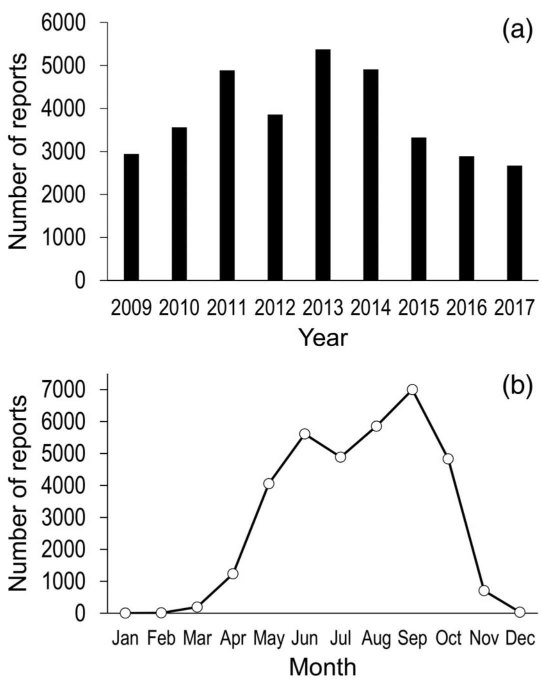

FIGURE 1 Yearly (a) and monthly (b) transitions of number of reports

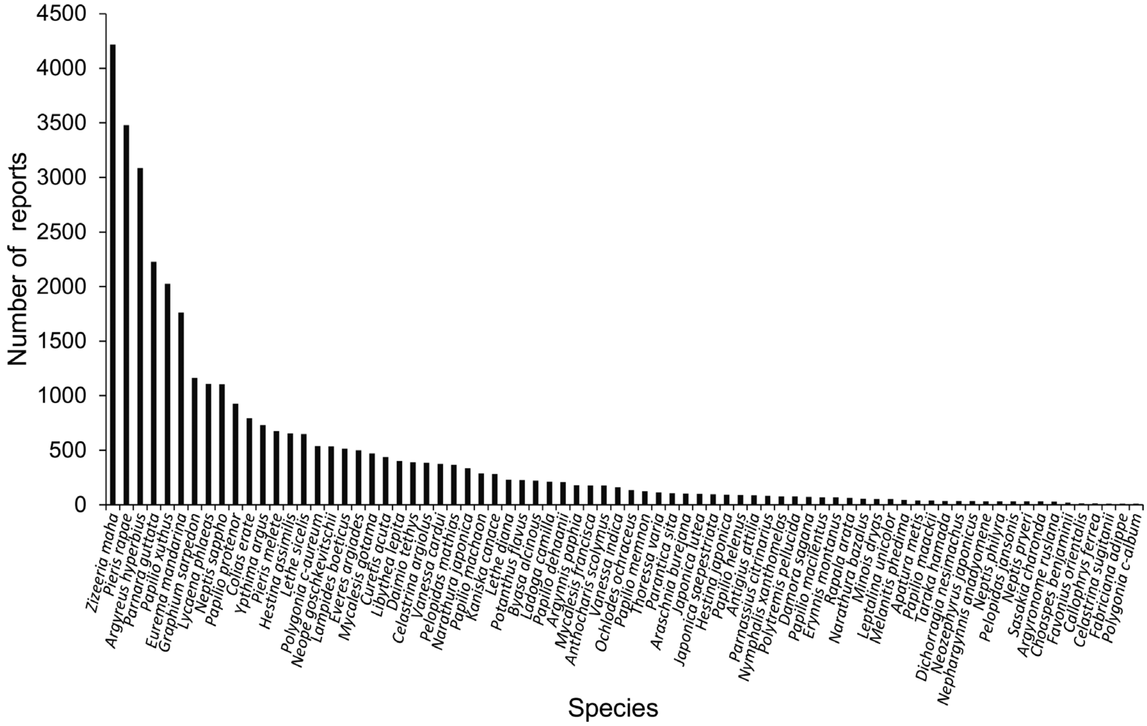

FIGURE 2 The rank diagram of the number of reports for individual species over the period 2009–2017. Species with fewer than 10 reports are not shown

be little varied spatially and temporally over the ranges this study covered. Taxonomic bias of our data, which is not large, would be able to be controlled by the statistical model with "family" as a random factor as mentioned below.

2.2 | Analysis and statistical testing

The numbers of reports of individual species were analyzed to test the "commonness hypothesis," that is, "the abundance or commonness of butterfly species depends on the prevalence of host plants and shortness of the reproductive cycle."

A generalized linear mixed model (GLMM) was used to test the effects of two categorical factors: "multivoltinism" and "utilization of cultivated plants" as larval food for the individual species.

From the compiled data, 34,415 reports were used for the analysis. The excluded data included duplicated reports, photographs of eggs or larvae, reports on *Taraka hamada hamada* because its larvae consume aphids, not plants, and on *Lampides boeticus*, *Melanitis leda leda* and *Danaus chrysippus chrysippus*, which are suspected to occur accidentally in the Tokyo region.

For individual species, "multivoltinism" was judged according to the description in an illustrated guidebook edited by the Japan Butterfly Conservation Society (2012). "Utilization of cultivated plants" was based on the description of host plants in Shirouzu (2006). Another variable suspected to affect the number reported, averaged forewing length (see Yoro, 2011), was included in the GLMM model as a continuous variable indexing the species body size. In order to control the effects of phylogenetic relations among species on the results, family was included as a random factor in the model.

The statistical analysis was conducted using R 3.5.1 (R Development Core Team, 2018). As the response variable (the number of reports of each species) was highly overdispersed from the assumption of a Poisson distribution (residual deviance/degrees of freedom >500); it was assumed to follow a negative binomial distribution with the log as the link function, using lme4 package (version 1.1-20).

3 | RESULTS

3.1 | Reported number and share for individual species

For the 90 butterfly species for which data were compiled between 2009 and 2017, the number reported for individual species ranged from one to more than 4,000.

Figure 2 shows the rank diagram for the number of reports for individual species over the study period. The most frequently reported species was *Zizeeria maha argia*, with 4,216 records, accounting for 12% of all butterfly records. It was followed in descending order by *Pieris rapae crucivora* (3,480, 10%), *Argyreus hyperbius hyperbius* (3,084, 9.0%), *Parnara guttata guttata* (2,226, 6.5%), *Papilio xuthus xuthus* (2,025, 5.9%), *Eurema mandarina* (1,763, 5.1%), *Graphium sarpedon nipponum* (1,164, 3.4%), *Lycaena phlaeas daimio* (1,106, 3.2%), *Neptis sappho intermedia* (1,105, 3.2%) and *Papilio protenor demetrius* (924, 2.7%). The records of the top 10 species account for around 60% of the total reports.

During the 9 years, there was no report on *Zizina otis emelina*, which is closely related to *Z. maha argia*.

3.2 | Factors contributing to the number of individuals reported per species

The variables "multivoltinism," "utilization of cultivated plants" and "body size" contributed significantly to the number reported for individual species (Figure 3 and Table 3). The effects of "multivoltinism" and "utilization of cultivated plants" were highly significant ($p < .001$). Moreover, body size had significant but weak negative effects ($p < .05$).

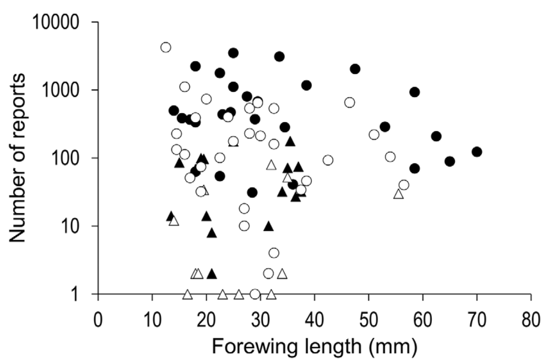

FIGURE 3 The compounded scatter diagram for the relationships between the reported number of individual species and body size (forewing length), by the species with (filled symbols) or without (open symbols) utilization of cultivated plants as larval host plants, and by those (circles) or not (triangles) of multivoltinism. The result of GLMM is shown in Table 3

4 | DISCUSSION

4.1 | Commonness hypothesis

We investigated the scientific value of the data collected by the "Tokyo Butterfly Monitoring" program by testing a simple hypothesis on the commonness or abundance of individual species. The GLMM revealed highly significant ($p < .001$) effects of "cultivated plant use" and "multivoltinism" supporting the hypothesis that the abundance of a species, surrogated by the number of reports, is dependent on the annual reproductive frequency and commonness of food plant(s) (Hardy & Dennis, 1999; Maezumi et al., 2010; Shreeve et al., 2001).

Our data did not satisfactorily escape from spatial, temporal and taxonomic biases, compared with those obtained by ordinary scientific studies with careful spatial or temporal sampling designs by expert scientists. However, the hypothesis we attempted to test in the present study is thought to be robust against such levels of biases as our data might be subjected, because the hypothesis is dependent largely on general biological traits of individual species, that is, host plant types and reproductive schedule, which are thought to be less varied within the spatial and temporal range of this study.

Weakly significant negative effect of "large body size" demonstrated in the statistical analysis would not be contradictory to the well-known general life-history theory that "*K*-strategist" characterized by several life-history traits including "large body size" is characterized by lower relative growth rate and thus incapable to colonize into new habitats (Pianka, 1970; Rockwood, 2015). Butterflies are likely to be no exception of the theory and especially large-sized Monarch butterflies of tropical rain forest have been textbook representatives of *K*-strategist of a stable competitive environment (Putman & Wratten, 1984).

In addition to cultivated plants, some small weedy plants are abundant in well-illuminated spaces, such as roadsides and open spaces of any size, although they were not included as a categorical variable in the statistical analysis. The main host plant of the top-ranked species *Z. maha argia* (syn. *Pseudozizeeria maha argia*) is *Oxalis corniculata*, which is a common weed that grows

TABLE 3 The result of the GLMM examining the factors affecting the number of reports on individual species

Explanatory variable	Estimate	Standard error	*z* value	*p* value
Intercept	3.0369	0.2830	10.732	<.0001
Cultivated plant utility	1.0067	0.2704	3.723	.0002
Multivoltinism	2.7066	0.2860	9.464	<.0001
Body size	−0.2783	0.1377	−2.022	.0432

on bare ground at roadsides and in any urban open space; its leaves are available almost year-round. The species is highly multivoltine with five to six annual reproductive cycles. Therefore, this species supports the hypothesis that the commonness of food plants and multivoltinism influence species abundance.

During the 9 years, there was no report on the closely related species *Z. otis emelina*, which is listed in the National Red List as "endangered" (Ministry of the Environment Government, 2014), and is suspected to be extinct in Tokyo (Tokyo Metropolitan Government, 2010). The habitat of its major food plant (*Lotus japonicas*) is well-illuminated spaces ubiquitous in rural landscapes, such as river floodplains or short grasslands, which were once abundant before the remarkable urban development of Tokyo. A butterfly database for the three westernmost wards of Tokyo, which was compiled with butterfly records collected by citizen scientists from 1923 to 1960 (past) and 1982 to 2008 (recent), suggests a marked decrease in *Z. otis emelina* between these two periods (Maezumi et al., 2010). A decline in its host plant due to urban development may be the major reason for its rapid decline or local extinction. While adaptive conversion of the host plant to the much commoner *Trifolium repens* was reported for the regional population in the Kansai area (Sakamoto, Hirai, Tanikawa, Yago, & Ishii, 2011), no such conversion has been reported for Tokyo. The species fate difference between the closely related species *Z. maha argia* and *Z. otis emelina* suggests that the commonness of food plants is critical for food plant specialists such as butterflies in a rapidly changing environment.

The second most abundant species (*P. rapae crucivora*) is dependent on the invasive alien weed *Orychophragmus violaceus* and a common ornamental plant *Brassica oleracea var. acephala*, which are cultivated in gardens and city parks.

A previous study demonstrated that "univoltinism" and the "inability to use cultivated plants as larvae food" were responsible for the local extinction of 16 butterfly species from the three westernmost wards from the 1960s to the early 2000s (Maezumi et al., 2010), which also supports the commonness hypothesis.

4.2 | Rapid changes in the butterfly community and appropriate target species

Compared with a past faunal dataset compiled by amateur scientists (Maezumi et al., 2010), the current monitoring data suggest rapid changes in the butterfly community.

The most conspicuous case is the third most abundant species in our monitoring data (*A. hyperbius*), which has a southern origin, and was absent from the past butterfly fauna (Maezumi et al., 2010). The invasion and increase in this species may be related to the change in the thermal environment of the megacity. Such a quick response of the species would be dependent on the abundance of host plants in the city environment, because the main food of *A. hyperbius* is a common ornamental plant, the pansy, which is widely planted in gardens and green spaces in the megacity.

Species less limited by the availability of food plants and with short reproductive cycles may also respond to anthropogenic environmental changes quickly. If a participatory butterfly-monitoring program was designed at the species level, species with common host plants should be chosen.

In conclusion, if well organized, participatory monitoring programs such as "Tokyo Butterfly Monitoring" can provide scientifically valuable data on some facet of rapidly changing biodiversity under "Anthropocene." Therefore, to study program designs to satisfy all scientific, social and individual participants needs is among the most important missions of current conservation ecology.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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