Using citizen science butterfly counts to predict species population trends

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Abstract

Citizen scientists are increasingly engaged in gathering biodiversity information, but trade-offs are often required between public engagement goals and reliable data collection. We compare population estimates derived from the first four years (2011-2014) of a short-duration citizen science project (Big Butterfly Count, BBC), to those from long-running, standardized monitoring data collected by experienced observers

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(UK Butterfly Monitoring Scheme, UKBMS), for 18 widespread butterfly species. BBC data are gathered during an annual, three-week period, whereas UKBMS sampling takes place over six months each year. An initial comparison with UKBMS data restricted to the three-week BBC period revealed that species population changes were significantly correlated between the two sources. The short-duration sampling season renders BBC counts susceptible to bias caused by inter-annual phenological variation in the timing of species' flight periods. BBC counts were found to be described well by measures for phenology and sampling effort. Annual estimates of species abundance and population trends predicted from models including BBC data and weather covariates as a proxy for phenology correlated significantly with those derived from UKBMS data. In validating the BBC counts, we show, for the first time, that citizen science data, obtained using a simple sampling protocol, can produce comparable estimates of insect species abundance to standardized monitoring data. Although caution is urged in extrapolating from this UK study of a small number of common, conspicuous insects, we demonstrate that mass-participation citizen science can simultaneously contribute to public engagement and biodiversity monitoring. Mass-participation citizen science is not an adequate replacement for standardised biodiversity monitoring but may have a role in extending and complementing it (e.g. by sampling different land-use types), as well as serving to reconnect an increasingly urban human population with nature.

Introduction

Citizen science, the participation of members of the public in gathering research and monitoring data, is increasing rapidly across many scientific disciplines, including biodiversity conservation (Dickinson et al. 2012; Follett & Strezov 2015). Public involvement in biodiversity recording and monitoring has a long history in some countries (Miller-Rushing et al. 2012; Pocock et al. 2015). Distinction can be made, however, between citizen science biodiversity projects that utilise standardised protocols to conduct systematic, repeatable sampling for long-term studies (e.g. the Breeding Bird Survey; Gregory & Baillie 1998) or for hypothesis-driven enquiry (e.g. Conker Tree Science; Pocock & Evans 2014), and schemes reliant on opportunistic sampling using relatively unstructured protocols (e.g. eBird; Sullivan et al. 2009). Opportunistic schemes with simple sampling protocols reduce barriers to participation (e.g. time commitment, prior knowledge) and may thus engage large numbers of new, inexperienced citizen scientists. While bringing benefits of increased sample size and public outreach, the data gathered may lack credibility (Riesch & Potter 2014; Lewandowski & Specht 2015). Standardised schemes may have much greater barriers to participation and therefore rely on fewer dedicated, skilled volunteers. However, the abilities of these participants to undertake biodiversity monitoring may be comparable with those of professional scientists (Chase & Levine 2016). Biodiversity citizen science projects often involve trade-offs between public engagement/education (itself a valid goal to counteract the ‘extinction of experience’; Soga & Gaston 2016) and the collection of reliable data for research (Chase & Levine 2016; Lakeman-Fraser et al. 2016).

Many aspects of citizen science biodiversity research have been examined, including the quality of observations (Lewandowski & Specht 2015), participants’ motivations (Hobbs & White 2012) and the development of new data analysis techniques (Bird et al. 2014). However, there have been few attempts to compare population trends generated by relatively unstructured sampling undertaken by mass-participation citizen science against those derived from long-term systematic monitoring and none, to our knowledge, involving terrestrial invertebrates. Here, we derive and compare species population trends from two contrasting citizen science recording schemes that run in parallel in the United Kingdom (UK) – the Big Butterfly Count and UK Butterfly Monitoring Scheme.

The Big Butterfly Count (BBC) is an annual survey of widespread butterfly species targeted at the general public (www.bigbutterflycount.org). It seeks to engage people with little or no prior experience of biodiversity monitoring, with aims of enhancing public awareness and interaction with nature, in addition to gathering species abundance data. In order to minimise barriers to participation the project employs a simple sampling protocol, comprising 15-minute counts of 18 butterfly species (and two diurnal moths) during a three-week period in the summer. Consequently, and thanks to a high media profile, BBC involves large numbers of people (mean= 47,636 p.a. 2013-2015). Since launching in 2010, BBC has achieved its aims of mass-participation and raising awareness but, given the target audience, likelihood of identification mistakes and simple method, do the counts provide any meaningful indication of population change among common butterflies?

We test the validity of BBC data for estimating species trends by determining whether population changes derived from BBC are comparable with those from the UK Butterfly Monitoring Scheme (UKBMS), a long-running monitoring scheme (initiated in 1976) with a robust, standardised recording protocol comprising weekly fixed-route counts for six months of the year at over 1000 sites. Although most

UKBMS data are gathered by volunteers, high levels of commitment and identification skills are required. Participants tend to be experienced butterfly observers, akin to 'amateur experts', and the high-quality data generated are used to produce population trend estimates for 56 of the UK's 59 regularly-breeding butterfly species, UK Government biodiversity indicators (Brereton et al. 2011a; Eaton et al. 2015) and numerous scientific research outputs (e.g. Dennis et al. 2013; Oliver et al. 2015b; Dennis et al. 2016; Thackeray et al. 2016).

Butterfly populations exhibit variation throughout the year as one or more broods emerge, and these phenological patterns vary year-to-year in response to the weather (Sparks & Yates 1997) and also show long-term trends due to climate change (Roy & Sparks 2000). As the BBC runs for only a three-week period each summer, inter-annual variation in counts for each species might result from differing phenology rather than real population changes. We assess temporal variation in phenology with respect to the BBC survey period, in order to determine its influence on estimates of annual change. Furthermore, we investigate whether population change estimates from the BBC, in conjunction with weather covariates, can provide an accurate indicator for how populations are performing. In the rapidly-expanding field of citizen science, our study provides a rare test of the validity of a mass-participation approach to biodiversity monitoring.

Methods

Big Butterfly Count

BBC was launched as a UK-wide citizen-science survey in 2010 and is run annually in late July and early August during the peak overall abundance of butterflies. In 2010 the scheme ran for 9 days, but from 2011 this was extended to a period of up to 24 days each year (Supporting Information), although participants can additionally submit counts through July and August. Due to this difference, 2010 data were excluded from analyses and we focussed on BBC data for 2011-2014. Participants count selected butterfly species (18 widespread butterflies, see Supporting Information, as well as two day-flying moths) for 15 minutes during bright weather. No training is provided to participants, who submit their sightings online, and minimal verification of sightings is undertaken. Counts can be undertaken in any UK location. If counting from a fixed position, the maximum number of each species seen at any time is recorded rather than an additive total, so as to reduce double-counting. BBC data are summarised in the Supporting Information, showing the scheme's rapid growth. Sightings are spatially referenced and the land-use type is recorded by the participant. The majority of count locations are gardens (65% on average, Supporting Information), with an average of 12%, 11% and 4% of counts undertaken in "fields", "other rural" and "woodland", respectively, and a small number in other land-use types.

UK Butterfly Monitoring Scheme

The UKBMS was established in 1976 and comprises a UK-wide network of line transects, typically 2-4 km long, where systematic, standardised counts of butterflies are undertaken (Pollard & Yates 1993). In 2014, 1223 UKBMS transects were monitored (Brereton et al. 2015). The scheme design allows for counts to be made throughout the main season for UK butterfly activity, with the core period being April-September. A 5m wide fixed transect route is walked weekly under specified times of the day and weather conditions and all butterflies seen are identified and counted. In practice c.30% of core-season weekly counts are missed (Dennis et al. 2013). Transect counts are used to generate annual indices of relative abundance, from which population trends can be calculated.

Comparisons of BBC and UKBMS data

We compared species abundance estimates from the two schemes in three ways, which increase in complexity. First we indicated good agreement through direct comparison of annual growth rates; we then investigated the effects of sampling effort and phenology; finally we provided a stringent test by examining whether UKBMS trends may be predicted over 36-year and 10-year periods (1980-2015 and 2006-2015 respectively) using BBC data and an appropriate weather variable acting as a proxy for butterfly flight season phenology.

The BBC and UKBMS are inherently different, independent data sets, and although sample locations are self-selected by participants in both schemes, the representation of habitats might differ. The overall UK coverage of each scheme is shown in Fig. 1. Most BBC counts are undertaken in gardens, whereas UKBMS locations are biased towards semi-natural habitats and often managed to benefit biodiversity (Brereton et al. 2011b). We compared the habitats covered by the schemes by summarising land cover data from 2007 (Morton et al. 2014) in the 1km

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squares sampled by each. For each UKBMS transect, the central 1km x 1km grid square was used to characterise the habitat.

Comparison of annual growth rates

To make an initial direct comparison between the two schemes, we limited the UKBMS data to counts made within the BBC date period each year and restricted the analysis to the 18 butterfly species primarily counted by the BBC (Supporting Information). Since BBC data are only available for a three-week period, by initially restricting the date period we can focus on directly comparing the two schemes in the absence of seasonal differences, for example due to multiple broods (that are sampled by the UKBMS).

Following Roy et al. (2015), we determined annual population growth rates for each species from the two data sets. In brief, we defined $\mu_{i,t}$ as the expected total count of a species at site i in year t across $v_{i,t}$ visits, and regarded this as the realisation of a Poisson random variable. Annual proportional changes in abundance were assumed to be the same across sites, such that we estimated an annual growth rate

$$R_t = \log\left(\frac{\mu_{i,t+1}/v_{i,t+1}}{\mu_{i,t}/v_{i,t}}\right).$$

which leads to

$$\log(\mu_{i,t}) = \sum_{j=1}^{t-1} R_j + \log(\mu'_{i,1}) + \log(v_{i,t}),$$

where $\mu'_{i,t} = \mu_{i,t}/v_{i,t}$. Standard generalised linear model (GLM) software, for example in R (R Core Team 2016), may be used to fit this model. However, BBC data comprise many sites, each requiring the estimation of a site parameter each year, and hence the model described is computationally challenging to fit to BBC data using standard GLM software, due to the amount of computer memory required. Therefore, we adopted a concentrated (or profile) likelihood approach (Morgan, 2008, p84; Pawitan, 2012, p61), which reduces the number of parameters to estimate, resulting in efficient model fitting (Dennis et al. 2016).

Using the notation $S_i = \log(\mu'_{i,1})$, apart from an additive constant, the log-likelihood may be written as

$$l = \text{Log}(L) = \sum_{i=1}^{S}\sum_{t=1}^{T}\left[-\exp\left\{\sum_{j=1}^{t-1} R_j + S_i + \log(v_{i,t})\right\} + \ y_{i,t}\left\{\sum_{j=1}^{t-1} R_j + S_i + \log(v_{i,t})\right\}\right]. \quad (1)$$

Then for site i we obtain

$$\frac{\partial l}{\partial S_i} = \sum_{t=1}^{T}\left[-\exp\left\{\sum_{j=1}^{t-1} R_j + S_i + \log(v_{i,t})\right\} + \ y_{i,t}\right],$$

and equating to zero gives

$$\boldsymbol{S_i} = \log\left\{\frac{\sum_{t=1}^{T} \boldsymbol{y_{i,t}}}{\sum_{t=1}^{T} \boldsymbol{v_{i,t}} \exp\left(\sum_{j=1}^{t-1} \boldsymbol{R_j}\right)}\right\}. \quad (2)$$

Substituting (2) in (1) results in a concentrated likelihood that can be maximised simply with respect to $\{R_j\}$. We maximised the likelihood using the optim function in R, with the BFGS algorithm (Nocedal & Wright 1999).

We estimated the net change, N, over T years for each survey by

$$\widehat{N} = \sum_{t=1}^{T} \widehat{R}_t,$$

where the variance of $\widehat{N}$ is the sum of all the entries of the covariance matrix for the growth rates. We adjusted for overdispersion by scaling standard errors using the square root of the ratio of the Pearson Chi-squared statistic to its degrees of freedom.

Effects of phenology and effort

Seasonality complicates the analysis of butterfly population data, as counts of adult butterflies vary through the year corresponding with life cycle phenology (Rothery & Roy 2001; Dennis et al. 2013, 2016). We used UKBMS data to establish how the BBC data are influenced by changes in flight period phenology. Seasonal abundance patterns for each species in each year were estimated by fitting an appropriate generalised abundance index model (GAI, Dennis et al. 2016) to the UKBMS data (without date restriction, in contrast to the previous section). For univoltine and bivoltine species, a phenomenological GAI assumes the flight period of each brood follows a normal distribution, with a corresponding mean flight date, μ, and associated standard deviation, σ. For species with complex seasonal flight patterns, which may not be modelled parametrically with ease, a GAI was fitted using a spline to describe the seasonal variation. The approach used for each species is given in the Supporting Information.

For each univoltine and bivoltine species we plotted the total BBC count per day along with estimates of the annual seasonal pattern from the UKBMS GAI. BBC counts from all dates were used, rather than only the official three-week period. We then explored whether BBC data can be described primarily by two factors: effort and phenology. For each species, a negative-binomial model with log-link was fitted using the glm.nb function from the MASS package (Venables & Ripley 2002) in R. The response was the total BBC count per day, and measures of effort (log(number of counts per day)) and phenology, based on the estimated seasonal pattern from the UKBMS, were covariates. Using the number of counts per day was also tested, however this measure is right-skewed, and therefore less satisfactory. The estimated seasonal pattern from the GAI (which sums to unity across the season) formed the measure of phenology for a given day and year. This is in anticipation of an association between higher BBC counts and greater effort and/or the timing coinciding with the peak in the species' seasonal pattern.

Predicting UKBMS species trends from BBC data

Next we assessed whether UKBMS species population trends may be described by the BBC data, using weather covariates as a proxy for phenology. We used a simple linear model to regress UKBMS abundance indices for 2011-2014 on BBC data, as well as weather covariates and the index in the previous year (auto-regression), to account for potential density dependence.

The UKBMS indices were estimated using a GAI, as in the previous section; in a given year the GAI produces a relative abundance, N_i, for each site i (Dennis et al. 2016). Given the variation in UKBMS sites between years, we fitted a Poisson GLM with year and site factors, and used scaled predicted year effects as indices of abundance (Dennis et al. 2013).

We used BBC data from the official period as a covariate in the linear model, taking the sum of the total counts per day scaled by the daily effort (defined as the log of the number of counts for all species for that day, as in the previous section). However scaling by the numbers of counts produced similar results.

Average monthly mean temperatures (°C, Parker *et al*. 1992) and total rainfall (mm, Alexander & Jones 2000) for Central England, for either spring (March - May) or summer (June - August), were used for weather covariates. All weather covariates were standardised to have zero mean and unit variance. The maximum correlation between any of the weather covariates was 0.67.

Potential longer-term (rather than for 2011-2014 only) effects of weather and density-dependence were also accounted for. A linear model was fitted to the GAI index for 1980-2014, in terms of the index in the previous year and each of the four weather covariates. The products of the slope coefficients and the covariates from each model were then included as optional offsets in the linear models, to allow for potential longer-term effects than those for 2011-2014 only.

Model selection was undertaken using the Akaike information criterion (AIC), using the dredge function in the MuMIn package (Barton 2016) in R. Given the small number of years for which BBC data were available, only up to two variables were allowed, and this was limited to only one weather covariate (either as a covariate for 2011-2014, or as an offset from weather for 1980-2014). The relative importance of the BBC and weather covariates was assessed using the relaimpo package (Grömping 2006) in R.

Each year UKBMS data go through a process of collation (from online and manual collection sources) and verification. Unverified UKBMS data were available for 2015, via the online submission system, hence a GAI was fitted to incorporate these data and estimate an index for 2015. We compared this index for 2015, estimated from observed UKBMS data, with the index predicted from the linear model with the lowest AIC. An abundance index for 2015 was also predicted for each of the candidate models, and we assessed the model with the prediction closest to the index from the observed UKBMS data.

Population trends were compared by fitting linear models to the index of abundance, where the index for 2015 had either been estimated from UKBMS data, or predicted from the best linear model. We estimated a percentage change over two time periods (longer-term for 1980-2015 and shorter-term for 2006-2015) and also calculated percentage changes with respect to the previous year. In doing so we assessed whether predicting the 2015 index from the BBC affects the overall UKBMS trend estimates.

Results

Comparison of BBC and UKBMS data

A greater percentage of 1km squares sampled in the BBC were classified as urban than for UKBMS transects (Supporting Information). This might be expected given that most BBC counts are undertaken in gardens. UKBMS squares represented a greater proportion of broadleaf woodland, but the two schemes showed similar coverage of arable farmland and improved grassland.

Comparison of annual growth rates

There was a significant correlation between the net species population changes from the two schemes for 2011-2014 ($\rho = 0.84$, $p < 0.001$, Fig. 2). There was also a significant correlation ($p < 0.01$) between each of the year-to-year changes (Supporting Information). In the brief period 2011-2014, 11 of the 18 species had significantly positive and three had significantly negative abundance change in the BBC, compared to 11 and six species with significant positive or negative change in the UKBMS, with the remainder showing non-significant trends (Supporting Information). Population changes estimated from the two schemes showed much similarity, although the BBC growth rates were less precise and tended to underestimate UKBMS growth rates; changes were generally of a similar magnitude, and were always of the same sign with the exception of Comma (*Polygonia c-album*) and Small White (*Pieris rapae*), and in no cases were the changes significantly different from zero and in opposite directions (Supporting Information). Nevertheless, there were significant differences in net change 2011-2014 between the two schemes for 11 species, and confidence intervals were on average twice the width for the BBC compared to the UKBMS (0.38 and 0.19 respectively). Estimates of overdispersion were greater than unity for both schemes (Supporting Information). The BBC showed a narrowing in the confidence intervals in 2013-2014 (average widths of 0.18 compared to 0.38 for 2012-2013), due to the increasing number of counts (Supporting Information).

Effects of phenology and effort

Overlaying total daily abundance of each species from BBC counts with phenology information from the UKBMS, revealed how BBC population estimates may be influenced by inter-annual variation in the timing of species' flight periods (Fig. 3 shows two exemplar species, others are provided in the Supporting Information). For Gatekeeper (*Pyronia tithonus*), the peak of the flight period is fairly central within the BBC recording period in 2011 and 2013, but falls at the end of period in 2012, and near the beginning in 2014. For Large White (*Pieris brassicae*) there is variation in the timing of the second brood, where in 2012 in particular the peak falls outside the BBC period.

Regressing the BBC counts on measures for effort and phenology showed good agreement between the counts and expected values, given the simplicity of the model used (Fig. 4 and Supporting Information). Residual deviance values suggested a good fit for the negative-binomial model compared to the Poisson case (Supporting Information).

Predicting UKBMS species trends from BBC data

The BBC was a covariate in the best model (in terms of AIC) for 13 of 18 species (Table 1), in conjunction with summer rainfall, spring temperature and spring rainfall each for three species, summer temperature for two, offset long-term spring rainfall and auto-regression for one species each. Of the 11 species where BBC and a weather covariate were in the best model, the relative importance of BBC exceeded the weather covariate for eight species (Supporting information). For five species BBC was not included in the best model, but auto-regression was important. The observed 2015 index of abundance was within the 95% confidence interval of the best model for 10 out of 18 species, and only four species showed major discrepancies (Fig. 5).

There were significant correlations between estimated population trends (Fig. 6), where the values for 2015 were from the observed data or predicted from the best model: $\rho = 0.99$ for 1980-2015, $\rho = 0.95$ for 2006-2015 and $\rho = 0.75$ for 2014-2015, where all $p < 0.001$. For 1980-2015, the difference between the two trends was < 5% for all species, and for 2006-2015 and 2014-2015, the difference was < 5% for 13 and 10 out of 18 species, respectively. Significant trends were correctly identified for the seven species with significant UKBMS trends for 1980-2015, although two further species were predicted to have significant trends. There was greater correlation between the trends when the model with the best 2015 prediction was used (Supporting Information).

Discussion

Citizen science appears to offer opportunities for large-scale, cost-effective biodiversity monitoring. However, concerns remain over the quality of observations gathered and the sampling protocols employed and, consequently, over the reliability of species trends and research outputs. This is particularly the case for citizen science projects that prioritise public outreach goals, as there is often a trade-off between mass participation and scientific rigour.

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Such concerns have rarely been tested empirically for biodiversity trends by comparing opportunistic citizen science data with standardised sampling. Munson et al. (2010) showed that eBird transect checklists were almost as accurate at predicting bird species occurrence as highly-standardised North American Breeding Bird Survey data. In contrast, Snäll et al. (2011) reported only weak overall correlation between opportunistic bird reports in Sweden and annual count data from a standardised transect-style survey, although correlations were stronger for species with greater inter-annual variation in abundance. In the only terrestrial invertebrate examples we are aware of, both Warren et al. (2001) and Oliver et al. (2015a) found correlations between UK butterfly species occurrence trends assessed from opportunistic recording scheme data and UKBMS population trends.

Population change estimates from the BBC and UKBMS using only counts from the official three-week BBC period showed significant correlation ($\rho = 0.84$). This compares favourably with the value of 0.75 obtained by Roy et al. (2015), when comparing population trends from the UKBMS with the Wider Countryside Butterfly Survey, which utilises a reduced-effort UKBMS sampling protocol in randomly-selected locations (Brereton et al. 2011b).

The temporal distribution of BBC counts showed potential mismatch with annual phenological variation, and the BBC data were found to be well described by measures of recording effort and phenology. Simple annual proportional changes in abundance calculated from the BBC could result from varying phenology and effort rather than true population changes, and may mask or falsely predict declines/increases. This demonstrates that the results of ‘snap-shot’ citizen science biodiversity projects, which often take place at fixed points during the year, are vulnerable to bias from temporal factors that are not normally measured in such projects, as well as from variation in participation.

Despite the limited number of years and lack of standardisation or verification, linear models based on BBC data and simple weather covariates were surprisingly successful at predicting the UKBMS abundance index for 2015, and consequently correcting for the effects of changing phenology. BBC was an important variable for 13 out of 18 butterfly species and the difference between the two trends was < 5% for all species over the period 1980-2015. Predictions of population trends were good even for species that are not straightforward to identify for inexperienced participants, for example three *Pieris* species (Large White, Small White and Green-veined White). The significant correlation and similar estimates of population trends between the two schemes validates the use of BBC data in assessing abundance change for these UK butterfly species. The analysis was based on only four years of BBC data and over time we might expect even better predictions from BBC.

Species with the poorest model predictions of the 2015 abundance index, and consequently greatest differences in trend estimates relative to the UKBMS, tended to be those with lower numbers of 1km squares recorded by the BBC (Supporting Information). Wider confidence intervals for the prediction of the 2015 index were also associated with species with lower numbers of BBC 1km squares. Species may be less well recorded by the BBC due to reduced population densities in locations such as gardens where most counts are undertaken. This may be addressed by encouraging BBC observers to sample other land-use types. Population trends for some species may also be better described by alternative climatic covariates. For example, trends for migratory Painted Lady (*Vanessa cardui*) and Red Admiral (*V. atalanta*) may be better explained by weather from parts of their ranges outside the UK.

This study concerns only 18 widespread butterfly species in the UK and, therefore, caution should be applied in extrapolating the conclusions to other taxa and areas. Compared to many invertebrate taxa, butterflies are conspicuous and popular, and, in the context of butterfly monitoring, the UK benefits from low species richness, high human population density and a tradition of amateur natural history recording.

From a biodiversity conservation perspective, the limitations of BBC relative to the UKBMS are clear. The UKBMS provides population trends for all but one of the threatened butterfly species on the British Red List (18/19 species), whereas BBC primarily counts just 18 common butterfly species (all also monitored by the UKBMS). Even in the UK, mass-participation citizen science is unlikely to provide reliable data on the large number of threatened, habitat-specialist invertebrates.

Nevertheless, the BBC data, validated by our analyses, provide the potential for additional or improved assessments of biodiversity change. For example, there is increasing interest in the biodiversity of urban areas, both as potential refuges for species whose habitats have been degraded in intensively-farmed countryside and for the opportunities it affords for human-wildlife interactions and associated human wellbeing benefits (Goddard et al. 2010; Shanahan et al. 2015). Sampling protocols developed for use in semi-natural habitat or open countryside may not be easily implemented in built-up areas and private gardens. The BBC samples more urban habitat than the UKBMS, and the majority of counts are undertaken in private gardens, hence the BBC could provide a new biodiversity indicator for the performance of butterfly populations in gardens and parks, providing a valuable tool to engage the public and managers of urban greenspace.

In addition, the sampling of private gardens and urban areas as part of BBC provides potentially useful population data for common butterfly species to complement UKBMS sampling of semi-natural habitat and the farmed landscape. While not of highest conservation priority, trends of common species are, nevertheless, of considerable interest due to the significance of such species to ecosystem function (Gaston & Fuller 2008). In the UK, the overall abundance of widespread butterflies decreased by 25% over 40 years (Fox et al. 2015) and many widespread species have significant negative population trends in the UK and the Netherlands (Van Dyck et al. 2009). Currently, the drivers of these declines are poorly understood. BBC and UKBMS data could be combined in an integrated analysis (Pagel et al. 2014) representative of a wider range of land-use types, although issues relating to variation in the scale and accuracy of the two surveys would require consideration, for example by weighting different likelihood components (Francis 2011).

In practice the financial costs of mass-participation citizen science versus standardised monitoring are an important factor, particularly where a new scheme is to be implemented. Both schemes incur considerable annual expenditure due to the essential involvement of professional staff, but the cost of running BBC is about a quarter that of the UKBMS. Aside from minor coordination, the primary cost of BBC arises from the need for media promotion to engage the public. Despite a larger overall cost due to requiring greater coordination, it could be argued that the UKBMS is more cost-effective, since data are collected for many more species, including those that are the main focus of conservation efforts. Both schemes also require a suitable online data system, however, particularly as the primary monitoring method for UK butterflies, the UKBMS incurs additional costs associated with data validation, which is not undertaken in the BBC.

The UKBMS operating costs are contingent on the assumption that an adequate network of skilled, trained volunteers already exists or can be mobilised quickly. Without this, the start-up costs and lead-in time for a monitoring scheme would be substantially greater than for mass-participation citizen science, e.g. if paid professionals were required (Carvell et al. 2016). As we have shown with BBC, mass-participation citizen science may, in some instances and with suitable adjustments (e.g. for effort and phenology), provide meaningful estimates of population trends for common, easily identifiable species. Even if this is not the case (or cannot be tested), through raising awareness and providing informal education, citizen science projects may provide a means to develop the necessary pool of skilled, engaged volunteers to enable the establishment of standardised biodiversity monitoring in areas or for taxa where these are currently lacking.

Despite relatively simplistic modelling and only a few years of available data, and contrary to the scepticism with which mass-participation citizen science is sometimes viewed, we have shown the BBC can produce population change estimates for common butterflies comparable to standardised monitoring data collected by skilled recorders. These results establish BBC as an example of a citizen science ‘win-win’ (Chase & Levine 2016; Lakeman-Fraser et al. 2016); a project focussed on outreach and public engagement that generates meaningful scientific output.

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Table 1. Summary of the best models and the selected covariates, in terms of the best AIC or closest 2015 predictions, compared to using observed UKBMS data. Percentage change estimates are given to 1 decimal place.

	Best fit		1980-2015		2006-2015	
Species	AIC	Prediction	Observed	Best AIC	Observed	Best AIC
Brimstone	bbc+SPRt	SUMr+of(auto)	35.9	35.1	-0.5	-2.2
Comma	bbc+SUMr	bbc+SUMr	10.9 *	10.9 *	-5.4	-5.5
Common Blue	bbc+SUMr	bbc+SUMr	-9	-8.9	5.2	5.5
Gatekeeper	bbc+SPRt	bbc+SUMr	-12.5 *	-12.4 *	-1.7	-1.3
Green-veined White	auto+SUMr	bbc+SPRt	-4.1	-2.8	6.6	11.2
Holly Blue	bbc+of(auto)	bbc+of(SUMr)	4.1	1.4	-6.1	-14.1
Large Skipper	auto+SPRt	auto+SPRt	-12.9 *	-13.5 *	-13.5	-15.6
Large White	bbc+SPRr	SPRt	-7.5	-7	-3.9	-2.3
Marbled White	auto+SUMr	auto+SUMt	-0.7	1.3	10.2	17.3
Meadow Brown	bbc+SPRt	SUMt+of(auto)	-4.7	-4.9 *	2.4	1.7
Painted Lady	bbc+SUMr	bbc+SUMt	-0.3	-4.3	-36.9	-46
Peacock	auto+SPRt	auto+of(SPRt)	-1	3	6.5	20.3
Red Admiral	auto+SPRt	auto+bbc	13.9	14.9 *	-11.9	-9.3
Ringlet	bbc+SUMt	of(SPRr)	12.3 *	11.3 *	7.9	5.2
Small Copper	bbc+of(SPRr)	SUMt+of(auto)	-14.2 *	-12.6 *	-11.8	-6.1
Small Tortoiseshell	bbc+SPRr	of(SPRr)	-27 *	-27.4 *	30.2 *	27.7
Small White	bbc+SPRr	bbc+of(auto)	-7.2	-6.2	0.1	3.3
Speckled Wood	bbc+SUMt	bbc+of(SPRr)	8.2 *	8 *	0.6	0

Note: SPRt, SPRr, SUMt and SUMr denote spring and summer temperature and rainfall, respectively, auto represents auto-regression and of represents an offset variable. Significance $p < 0.01$.

Figure 1. Locations of UKBMS (1462 transects) and BBC (65197 1km squares) records from 2011-2014.

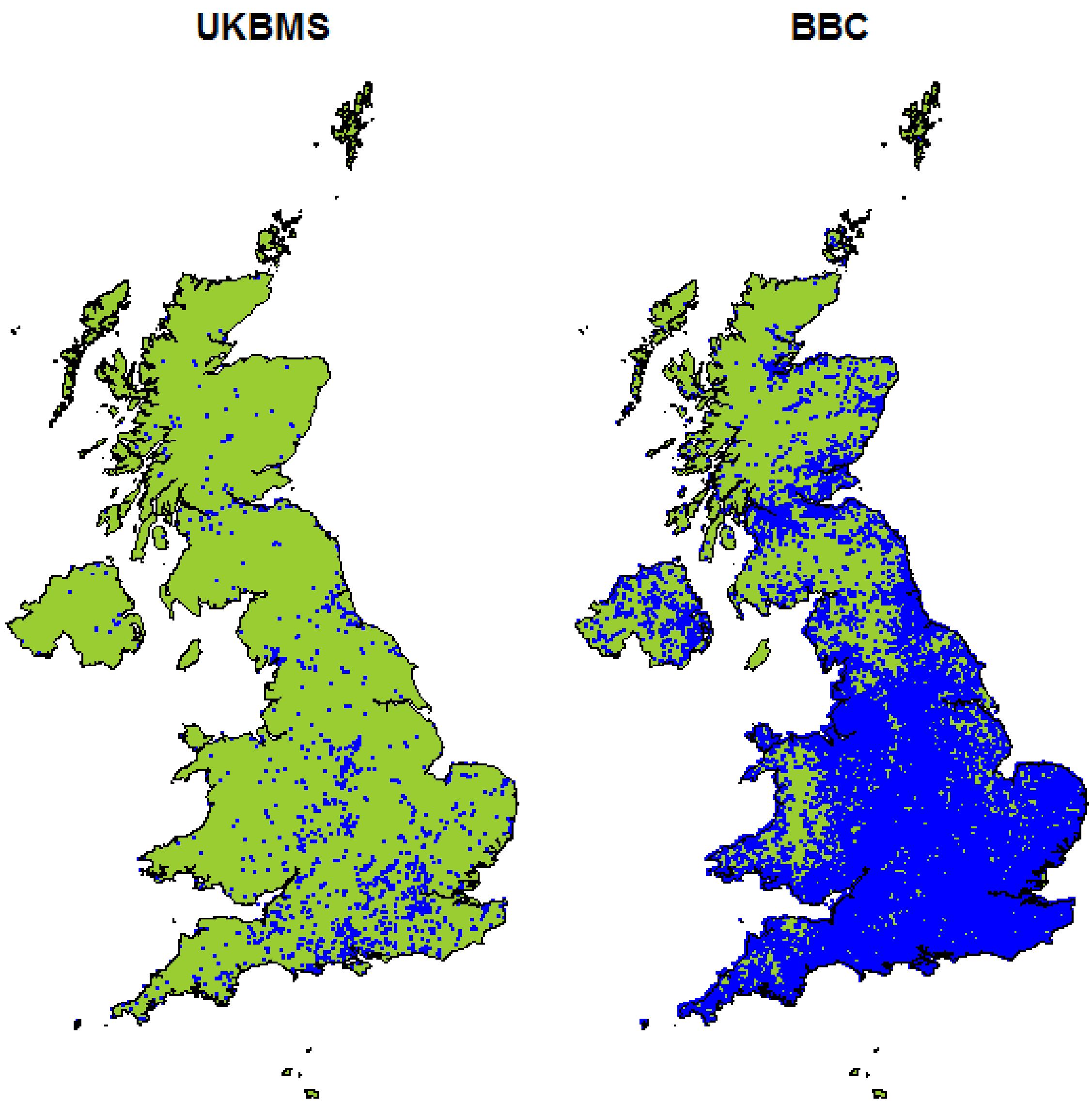

Figure 2. Comparison of estimated log growth rates from the BBC and UKBMS for 2011-2014. Error bars represent 95% confidence intervals. Solid grey lines represent zero growth, the dashed line represents equal growth rates from the BBC and UKBMS, and the solid black line shows the fitted linear regression between the BBC and UKBMS growth rates. Letters represent species with the greatest differences (ST=Small Tortoiseshell, CB=Common Blue).

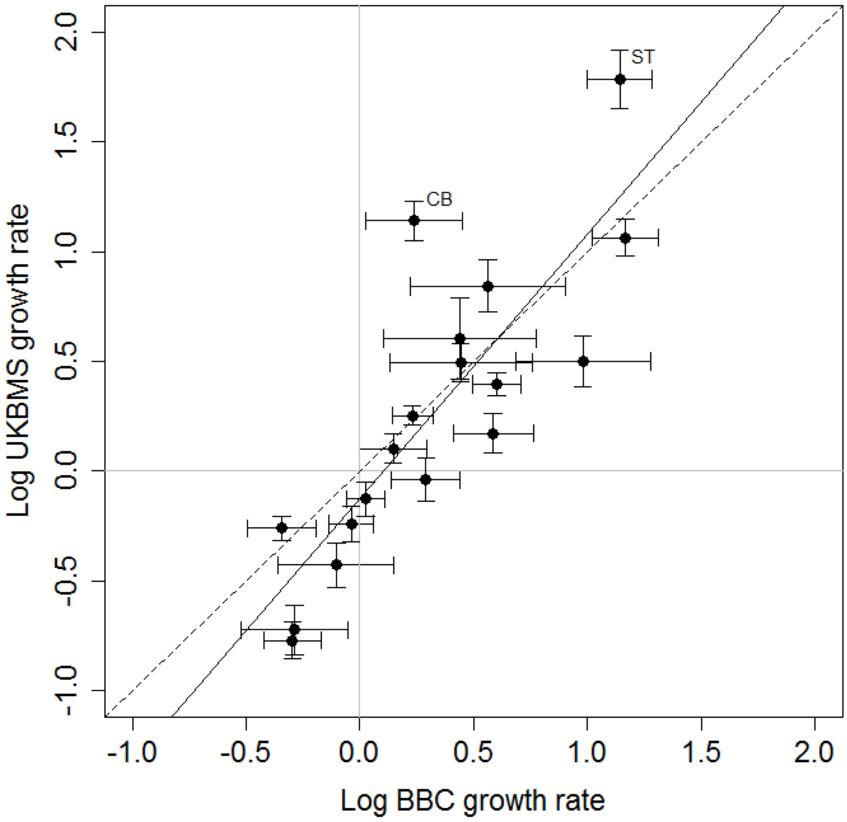

Figure 3. Total counts of BBC records per date in each year, where day 1 corresponds to 1st April. Mean flight dates, estimated from a GAI, are shown, as well as +/- twice the standard deviation (dashed lines, green=1st brood, blue=2nd brood). Red lines on the x-axis indicate the official BBC period for each year.

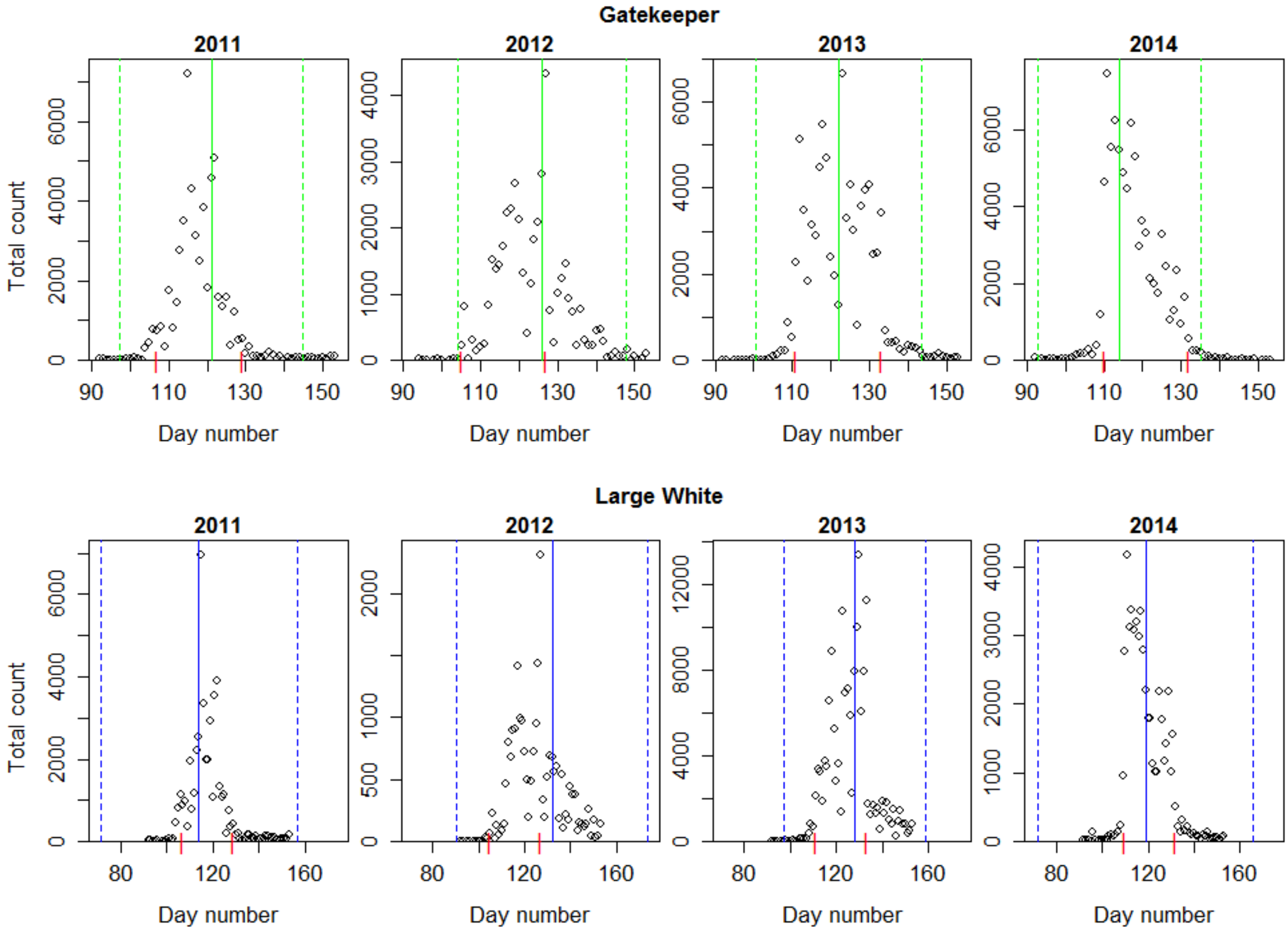

Figure 4. Total BBC count per day versus the expected value from a negative-binomial model with log-link where the response is the total BBC count per day and measures of effort (log number of counts made) and phenology (from the corresponding GAI curve) are covariates. Three example species are given: Gatekeeper (univoltine), Large White (bivoltine) and Comma (multivoltine). The black line is the 1-1 line and the green line is a fitted linear regression through the points.

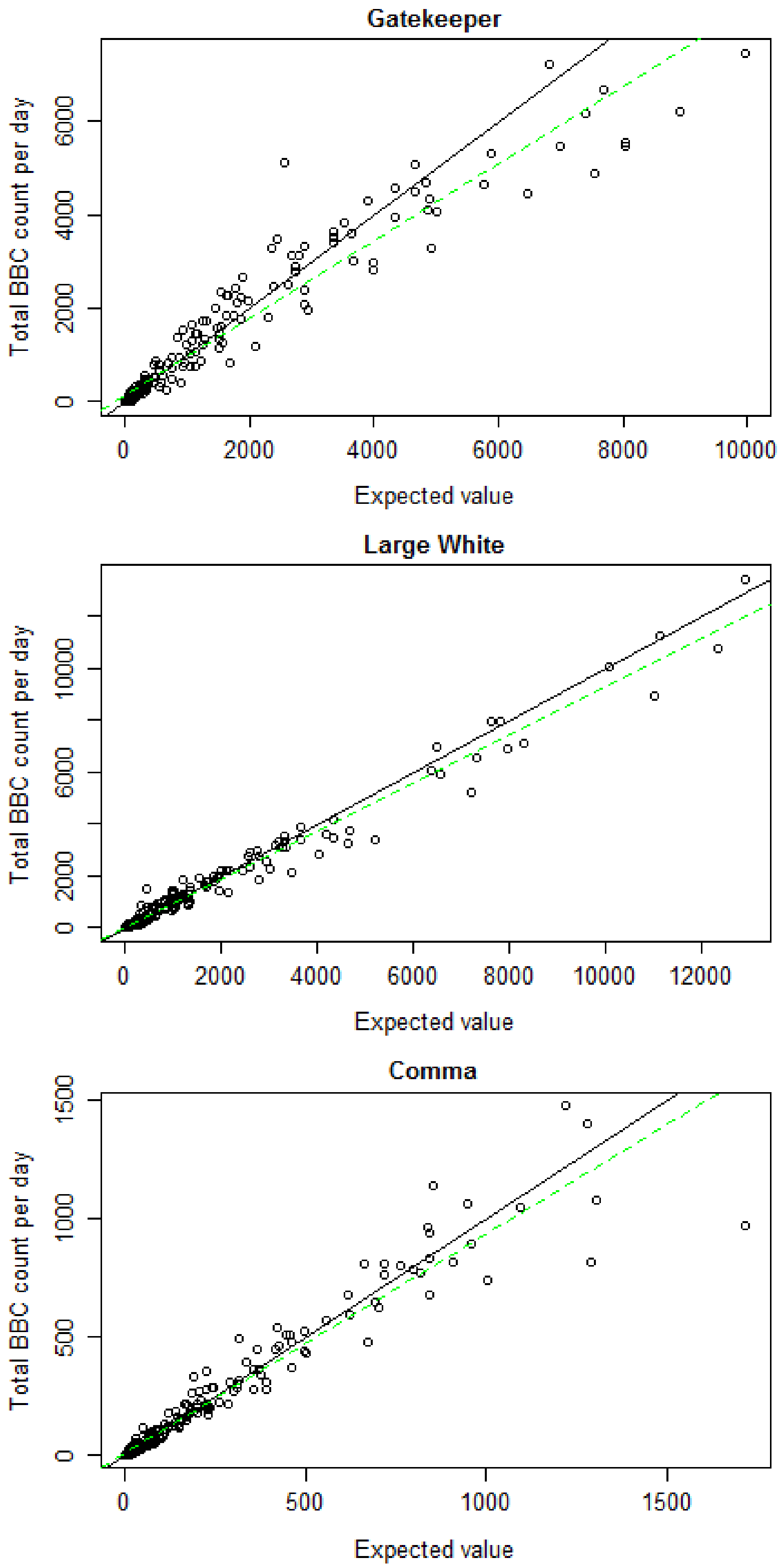

Figure 5. Comparison of the GAI index from UKBMS data (black) and predicted values from the best model in terms of AIC (red), with 95% confidence intervals for the 2015 prediction.

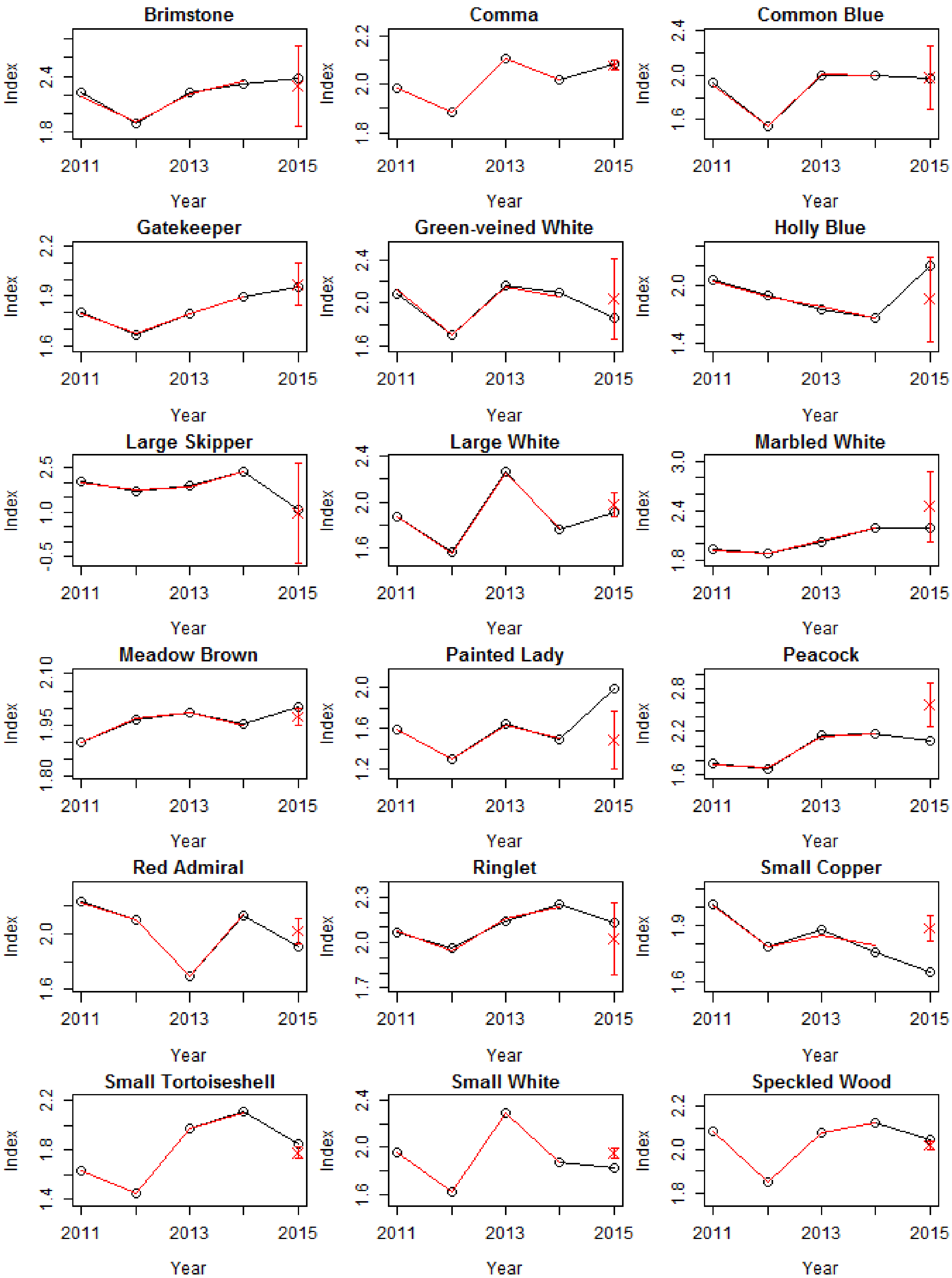
Brimstone
Comma
Common Blue
Gatekeeper
Green-veined White
Holly Blue
Large Skipper
Large White
Marbled White
Meadow Brown
Painted Lady
Peacock
Red Admiral
Ringlet
Small Copper
Small Tortoiseshell
Small White
Speckled Wood
Index
Year
2011
2013
2015

Figure 6. Comparison of linear trends from the GAI index, where 2015 is from observed data or predicted from the best model in terms of AIC. Letters represent species common names (see Supporting Information). Solid grey lines represent zero percentage change and the dashed line represents equal trends.