IS PHOTOGRAPHIC RECORDING INFLUENCING PUBLISHED TRENDS IN THE RELATIVE FREQUENCY OF INVERTEBRATES?

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ABSTRACT

Occupancy models are widely applied to opportunistic data to calculate trends for a variety of organisms. At the same time, there has been a considerable change in the way opportunistic data are generated: there has been a shift away from retained specimens identified by microscopy, in favour of digital photography. We have suspected for several years that this increase has affected the outputs of occupancy models.

To test this hypothesis, we applied the FRESCALO occupancy model to data compiled by the British Hoverfly Recording Scheme. In one analysis the whole dataset was used before the model was re-run using a sub-set in which photographic records were excluded. In so doing, we detected divergence in the trends for some species beginning to appear over the last decade, during which photographic recording has become prevalent.

The overall divergence was sufficient to significantly over-estimate the proportions of species believed to be in decline, but it had less impact on the numbers of increasing species (although the species list changed). These responses suggest that photographic recording is having an important effect on the composition of the dataset and therefore on analytical outputs.

We highlight the need for greater precision in recording the methods used by record contributors. Such a system would help to compartmentalise opportunistic datasets in which the methods used by recorders are widely heterogeneous. This approach would allow the development of a new generation of occupancy models with weighting to take account of significant biases introduced by recording technique. Once a sufficiently long time-series of photographic data has been assembled, it may be used independently to investigate some aspects of environmental change. The evidence suggests, however, that photographic recording can never completely replace the comprehensive data assembled by recorders who retain specimens for microscopic examination.

INTRODUCTION

Demand for information on trends in the natural environment in the UK (and globally) is increasing, especially as there is concern about pollinators (Potts *et al.*, 2010; Powney *et al.*, 2019; Soroye, Newbold & Kerr, 2020). In contrast to many parts of the world, the UK is extremely data-rich. For some taxa, such as breeding birds, there are long-term monitoring programmes that provide year-on-year comparative data based on broadly comparable methods. They convey an important message about breeding success and the state of bird populations (Harris *et al.*, 2017). Long-term monitoring programmes for butterflies and moths (Fox *et al.*, 2013; Fox *et al.*, 2015) are also available. Standardised data for other taxa are generally lacking but a growing interest in biological recording builds on a long legacy of opportunistic data accumulation. These data range from single species records from a given location and date, to complete (long) lists of species recorded on a given date at a given location (and with many intermediate permutations). These data are supplied by a wide variety of sources, including some 'professional' surveys but mainly from non-vocational specialists and volunteers, often referred to as 'Citizen Scientists' (Silvertown, 2009; Roy *et al.*, 2012; Science Communication Unit, 2013).

There are 85 voluntary recording schemes in the UK (Pocock *et al.*, 2015), many of which were initially intended as mapping projects. Some, but not all, make data available through the National Biodiversity Network (NBN) (National Biodiversity Network, 2017) and hence through the Global Biodiversity Information Facility (GBIF) (Flemons *et al.*, 2007). Most schemes are run by one or two 'scheme organisers' who are responsible for working with a wide range of recorders, providing the necessary validation and verification of records, and assembly of the dataset. The Hoverfly Recording Scheme (HRS) (Ball *et al.*, 2011) is one such voluntary scheme. It was established in 1976 (Stubbs, 1990) and at the time of writing held 1.25M records from Great Britain. It is the largest dataset for GB invertebrates after Lepidoptera and Odonata and has grown extremely rapidly in the past 12 years (Fig. 1). These datasets are particularly important because they underpin research into pollinator and wildlife trends (e.g., Biesmeijer *et al.*, 2006; Potts *et al.* 2010; Oliver *et al.*, 2015; Carvell *et al.*, 2016; Outhwaite *et al.*, 2018; Powney *et al.*, 2019; Outhwaite *et al.*, 2020).

Whilst demand for environmental data is increasing, there is also a growing body of opinion that lethal methods of data assembly are incompatible with modern conservation thinking (Pohl, 2009). This issue regularly emerges in social media such as specialist Facebook groups (e.g., see UK Hoverflies, 2020). We have also found that there has been a growing trend amongst conservation managers for refusal of permission to use lethal methods or even to use a sweep net (Morris, 2020). These pressures are un-quantified but, in our case, have resulted in the abandonment of proposed field studies. There is at least a perception that lethal methods are outdated and that photography is the new paradigm. This paradigm shift was originally discussed by Jepson (2005), who postulated that it would circumvent the need for taking specimens. In the ensuing years, digital photography has evolved to the point where it is realistic for a non-specialist to record all that they see by posting pictures on social media. If placed on the right 'site' they will get a reliable identification of at least some of the target animals and plants.

The degree to which different taxa are identifiable from photographs varies for several reasons. In some Orders/Families the critical characteristics are small or obscured. For example, the scutellum of many bees is often distinctively rugulose but covered with hairs that make the feature difficult to interpret without varying the angle of view and high magnification. In other cases, such as within some parts of the Coleoptera, Diptera and Hymenoptera, features within the male genitalia are critical. Geography can also play a part in the determination, as island faunas (such as GB) are often smaller than those of an adjacent bigger land mass. For example, the hoverfly fauna of GB and Ireland comprises 283 (known) species whereas van Veen (2004) keys out 500 species from Northwest Europe.

Furthermore, some animals are comparatively large and easy to depict in macro-photography (e.g., butterflies), whereas others, such as many flies, range from 1mm to several centimetres. Depicting the smallest at an adequate resolution is very different to that of the largest animals. Furthermore, in some taxa such as many butterflies and (some) moths there are patterns that make identification from

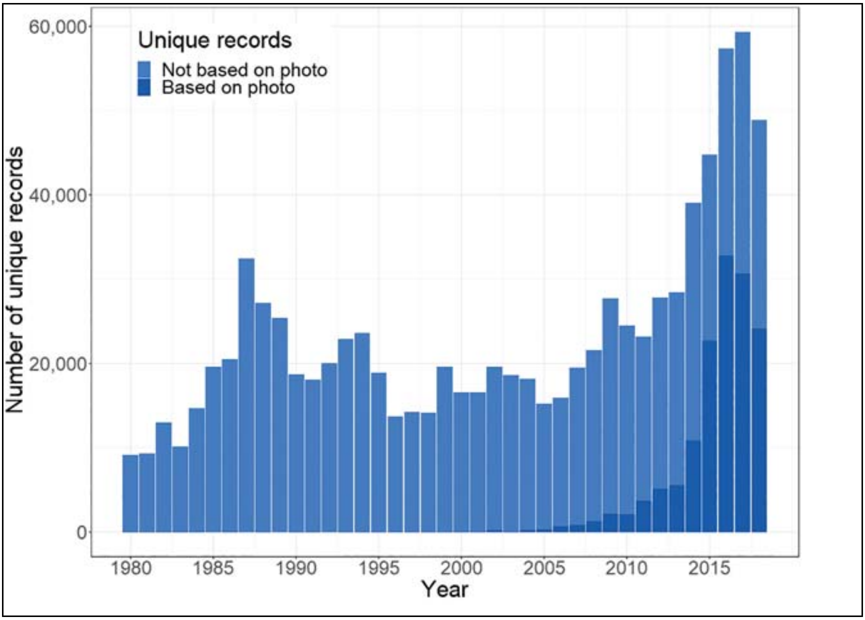


Fig. 1. Number of unique GB records submitted each year to the Hoverfly Recording Scheme categorised by whether or not they were based on photographs.

photographs possible. Consequently, although the possibility of generating reliable data for some taxa is good, that principle cannot be applied universally. The analytical problems arise within taxa that are either very small, have high levels of morphological variability and/or require detailed microscopic investigation to arrive at a reliable determination. Nevertheless, numerous on-line facilities exist to facilitate identification of many organisms from photographs.

The most suitable web sites are those that are visited by specialists in the relevant taxonomic group. The resulting determination is of course subject to relevant identification features being represented adequately but will often result in an identity at least to genus and often to species (Morris, 2019). For many taxa this opportunity is available through *iSpot* (Silvertown *et al*., 2015) but there are increasing numbers of Facebook groups linked directly to specific recording schemes. The Hoverfly Recording Scheme (HRS) has been one of the most active proponents of working with photographic recorders. Its Facebook group, UK Hoverflies (2020), has been used to improve levels of both spatial and temporal recording as well as providing mentoring for recorders to improve their taxonomic and ecological skills (Ball *et al*., 2017).

Van Strien, van Swaay & Termaat (2013) compared standardised and opportunistic data for butterflies based on the same grid squares and years. The resulting analysis suggested that strong trends were rarely missed in opportunistic data. They therefore argued that occupancy models control for the common biases encountered with opportunistic data such as those assembled by the HRS. In addition, they postulated that opportunistic data would become an important source of information to investigate distribution trends in many taxa. Isaac *et al*. (2014) also reviewed the methods used to investigate trends derived from large-scale opportunistic datasets and recommended the use of FRESCALO (FREquency SCAling LOcal) (Hill, 2012) or other occupancy models.

We have suspected for some time that changes in data sources would have an impact upon the data used by a wide range of research groups. In the case of the HRS three distinct epochs can be recognised:

The collection-based stage (pre-1976 when the HRS was launched (Stubbs, 1990). Data for the years preceding this date result from recorders extracting data from their collections and notebooks. The numbers of records generated were small (considerably fewer than 10,000 pa^{-1}) and the recorder base largely comprised experienced taxonomists and museum specialists. This paradigm continued for several more years (at least until the early 1980s).

Broader interest in hoverflies that was underpinned by the publication of a new and much more accessible monograph, with excellent illustrations. This period (˜1983 to ˜ 2010) represented a paradigm shift in the range of people who would tackle hoverflies, which hitherto had mainly been the preserve of specialists with access to extensive comparative material. The illustrations undoubtedly drew in recorders who made identifications by matching pictures rather than by using keys, and the data started to be fill out for more recognisable and abundant species. Nevertheless, the numbers of recorders remained comparatively low and stable. Until 2010, 50% of the data were supplied by just 20 people (Ball *et al*., 2011). However, the influence of digital photography had started and the numbers of recorders were accelerating (Fig. 2).

The age of digital photography, whose origins were in the mid-2000s and which became increasingly dominant from 2013 onwards. This growth was partly because digital technology rapidly improved and more people were able to use such cameras. Increased use of social media through 'smart' phones added to the process and as yet we see no sign of the trend flattening out.

Our initial concern was that the numbers of 'difficult' species represented in the dataset were declining. Thus, even before the advent of modelling we were concerned about under representation of 'difficult' taxa within the dataset. The differences between data supplied by modern recorders and those of the 'traditional recorder' are now pronounced. Figure 2 compares the representation of the Tribe Pipizini and difficult *Cheilosia* in the full dataset and by photographic contributors. This graph not only demonstrates the divergence of representation of difficult species as photography has become more dominant; it also shows the very close correlation between datasets prior to the publication of Stubbs & Falk (1983). As the use of opportunistic data in modelling has intensified, we have increasingly worried that the outputs of models have been influenced, not only by genuine declines (and increases) but also by dramatic changes in the composition of the data.

These changes can be turned into a conceptual model that argues that the drivers of trends generated by models include data composition factors as well as genuine biological change. This paper investigates the hypothesis that changes in recording methods have the potential to influence the outputs of models that use opportunistic data to generate wildlife trends. Bearing in mind the recommendation of Isaac *et al*. (2014) we used FRESCALO to investigate trends in the relative frequency with which species were observed between 1980 and 2018.

MATERIALS & METHODS

Data source and its development

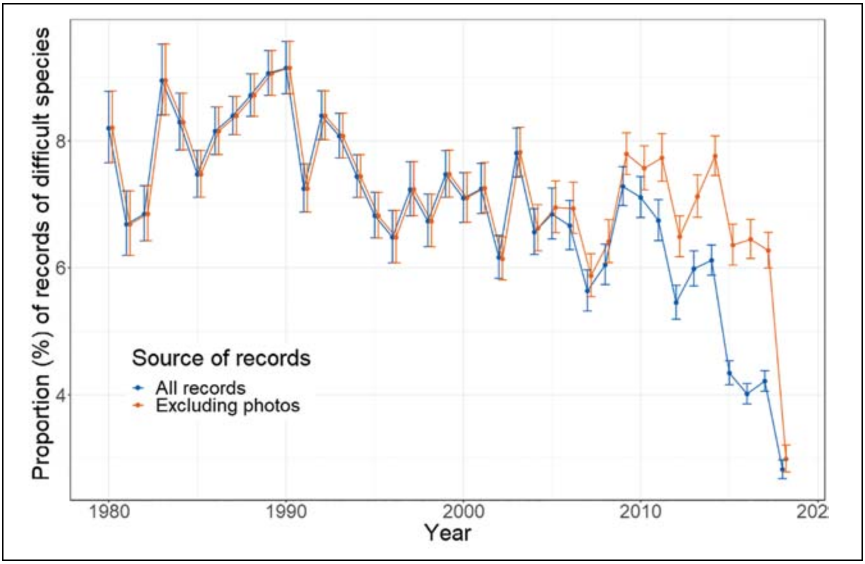


Fig. 2. The proportion (%) of records received by Hoverfly Recording Scheme between 1980 and 2018 which were of species in the tribe Pipizini and the genus *Cheilosia* (except for *C. illustrata* (Harris) which is readily identified and photogenic). These comprise 58 species which are black, not obviously hoverflies and often difficult to identify. The error bars show 95% confidence intervals for the proportions.

This analysis is based on data assembled by the British Hoverfly Recording Scheme (HRS). At the time of this analysis, the total dataset comprised 1.15M records. Data sources range from specialist taxonomists to non-specialist observers. Almost all of the data derive from the voluntary sector; comparatively little (< 5%) comes from academic or 'professional' sources but a substantial number of the taxonomically competent contributors were once employed as ecologists, wildlife specialists or even entomologists. Basic data that make up a record comprise:

The species name

Date of recording

The location from which the animal was recorded, including the Ordnance Survey of Great Britain grid reference (usually at 1km or greater precision)

The name of the recorder and the name of any additional determiner

Some data are more comprehensive and may also contain:

The life stage/gender of the animal (when this is not given, we assume the stage observed was an adult)

Numbers seen

Relevant observations such as flower visits or behaviour (e.g., in copula or defending territory)

The method of collection such as by visual recording, sweep netting or photography (when this is not given, we assume it was a visual, field record)

The URL for photographic records and reports extracted from the internet is routinely recorded in a free-text comment in the HRS database. This system allows us to identify records from photographic and web-site sources because they are flagged with recording method ̂photographed¤ and/or by looking for a URL in the comment (by searching for substrings such as "http://", "https://" and "www."). Consequently, it is possible to separate records into two subsets referred to here as "*all records*" and "*excluding photographic*". It should be noted, however, that the absence of a comment or URL does not mean that the data have been recorded by traditional methods using net, pooter and microscopic examination. Consequently, the analysis for "*excluding photographic*" should be regarded as potentially heterogeneous but with a lower preponderance of data derived from the taxonomically competent recorders.

A total of 976,670 'unique records' (i.e., unique combinations of species name, date and grid reference) of the Syrphidae (Diptera) were extracted from a total of 1,146,194 within the HRS database (on 15 March 2019). This lower total represents what we believe to be the 'real' records when duplications have been eliminated.

Data verification

A series of standardised verification routines are applied when absorbing newly supplied data. Firstly, the species recorded are assessed to determine whether there are records that fall outside the known flight period or the recognised biogeography. If there are questionable records, the methods and taxonomic ability of the recorder are assessed (are they well-known to the scheme organisers; are their methods known; are there indications from the composition of species lists?) In other words, are there reasons why either individual records or the entire dataset should be rejected? In extreme cases, the entire dataset is archived but not included in the HRS dataset. Where possible, records are challenged and problem specimens requested for examination. The grid reference, date and ancillary information is then checked for anomalies. In recent years, this has become a semi-automated approach using 'Record Cleaner' (National Biodiversity Network, 2020). Once the data have been adequately scrutinised, they are imported into the database 'Recorder' (see NHM Scientific Research Centre, 2020).

Although datasets such as the HRS undergo a lot of scrutiny and 'validation', it is inevitable that some misidentifications are incorporated. The proportion of inaccurate records prior to 2011 cannot be estimated. Since digital photography started to dominate record submission, there can be greater certainty that data extracted directly from iSpot, Flickr and the UK Hoverflies Facebook page are reliable. These data are compiled by one of us (RKAM) who ensures that the animal concerned is correctly identified. This approach ensures a consistent level of reliable identification, which is not the case in most social media (Silvertown *et al,*. 2015).

Application of the FRESCALO occupancy model

Our FRESCALO analyses require two inputs:

1. A set of unique observations consisting of hectads (10×10 km squares of the OSGB grid), hoverfly species and the year of observation.

2. A set of "neighbourhood weights" calculated separately from the main analysis. For each hectad, this consists of a list of 50 nearby hectads with a weight calculated from a combination of proximity to the target hectad and a measure of environmental similarity. Thus, hectads which are both physically close to, and which offer a similar environment to the target hectad receive a weight closer to 1 whilst those that are distant or offering a different environment, receive a low weight. Hill (2012) used a measure of similarity between grid squares based on plant species lists to calculate his neighbourhood weights. We used similarities of environmental

conditions based on the Institute of Terrestrial Ecology (ITE) Land Classification 2007 (Bunce *et al.* 2007), a soil classification from the European Soils Database (Panagos *et al*., 2012), gridded weather observations from the Meteorological Office (Met Office, Hollis, & McCarthy, 2017), and topographical information (altitude, slope and aspects) derived from NASA's Shuttle Radar Topography Mission (NASA JPL, 2013).

FRESCALO accumulates a list of species for each neighbourhood and calculates the weighted mean frequency of each species. The contribution of each hectad in a neighbourhood will be the number of records of the species in question multiplied by that hectad's weight. The recording effort in the neighbourhood is then quantified as the sum of all these weighted numbers of records, and a similar sum accumulated for each species. The weighted relative frequency of a species in a neighbourhood is then the overall weighted sum divided by that for the species. It then essentially fits a species discovery curve whose initial shape is controlled by a supplied parameter, phi. This is used to estimate the relative frequency of each species, corrected for the recording effort in the neighbourhood – termed the "TFactor". Finally, these values for each neighbourhood are averaged (and standard deviation calculated) to give an overall value for each species and year. The default value for phi is 0.75 which is derived from Hill's analysis of Bryophyte data. There is no reason to expect that this value should be appropriate for hoverflies. One of the outputs from the analysis is the 98.5% percentile of the values of phi actually fitted to the neighbourhoods. One would expect this value to be close to the parameter value supplied. If this is not the case, phi can be adjusted, and the analysis rerun. A value of phi of 0.71 was found to be appropriate for our data (resulting in a 98.5% percentile within 0.005 of this value).

The trend for a given species was quantified by calculating Spearman's rank correlation (rho) between TFactor and year. If the estimated p-value for rho was less than or equal to 0.05, the trend was deemed "significant" and the sign of rho determined whether it was "increasing" or "decreasing", otherwise the trend was categorised as "no change".

Two FRESCALO analyses were carried out using unique combinations of speci + es, hectad and year derived from these two datasets between 1980 and 2018:

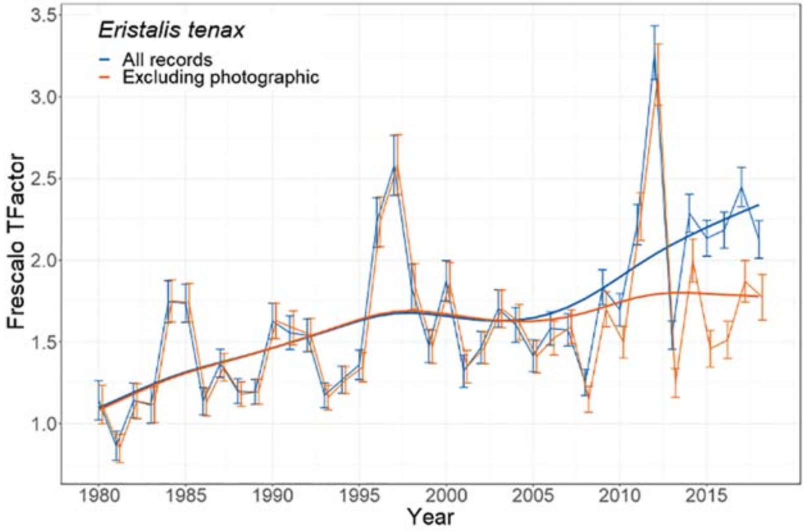
A 'complete' dataset (i.e., the combined data from photographic recorders and traditional recorders)

A (smaller) dataset in which records that could be identified as coming from photographic sources was excluded. This 'exclusion' process identified records in which a URL noted in the free text section indicates that it had been extracted from a photograph posted on relevant social media. The process also excluded records where the method used specifically stated 'photographed'. This second dataset more closely resembles the dataset that might have existed without the steep rise in record submission seen in Figure 1. It does not, however, mean that the dataset would have been analogous because several of the original 20 key contributors have died in the past 15 years.

Analysis was carried out using R (R Core Team, 2019) and R-Studio (R Studio Team, 2018), except that FTESCALO calculations were made using an R package written by SGB (rFrescalo) by converting Hill's original FORTRAN code.

To investigate the impact of the difference between species in their attractiveness to photographers, a Chi-squared test was also carried out. The total number of records received and the numbers derived from photographs from 1980 to 2019 were separated into eight five-year periods; from which the proportion of records resulting from photographs was calculated. Assuming that all species are equally photogenic,

(a)



(b)

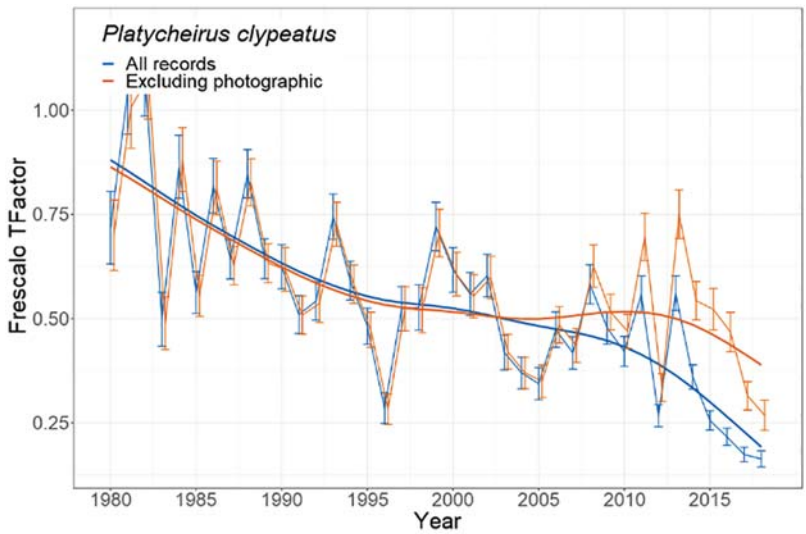


Fig. 3. Examples of FRESCALO analyses to show extremes of the effects of the increase in the proportion of photographic records in recent years. The plot shows the FRESCALO TFactor vs year with the Standard Deviation of the TFactor indicated by the error bars. The curves show smoothing splines (5 d.f.) fitted to the data. (a) *Eristalis tenax* (L.); (b) *Platycheirus clypeatus* (Meigen).

the expected number of records derived from photographs was estimated by multiplying the total numbers of records of a given species by those proportions and compared with the actual number of photographic records received, from which a Chi-square value calculated. Where the expected number of photographs is significantly higher than the actual numbers, it can be inferred that the species is not attractive and/or available to photographers whereas, if the expected numbers are lower than observed, a species is clearly favoured by photography.

RESULTS

When the FRESCALO model was applied to the entire Hoverfly Recording Scheme dataset, the outputs were broadly in line with what has been found by other investigations into a combination of taxa (e.g., Hayhow *et al.*, 2019; Oliver *et al.*, 2015), i.e., about half of the species show a significant decline in their frequency. Records of this sort do not, however, indicate the degree to which abundance or biomass has changed and consequently they cannot be compared with such data.

Figure 3 shows two extreme examples from the results: *Eristalis tenax* (L.) is a very common, large, obvious and easily identified flower visitor and is the third most frequently photographed hoverfly. The "*All records*" results clearly diverge above the "*Excluding photographs*" results from about 2005. *Platycheirus clypeatus* (Meigen) is also a widespread and common species, but is small and cryptic, usually requiring sweeping the vegetation with a net to locate and is seldom seen at flowers. It requires close examination, at least with a hand lens and preferably under a microscope, for firm identification and is not often photographed (ranking 131^{st} most photographed). Its analysis shows the opposite trend with the "*All records*" results increasingly diverging below the "*Excluding photographs*" results from around 2004.

The examples in Figure 3 both suggest long-term trends in the relative frequency with which these species were observed, an increasing trend in the case of *E. tenax* and a decreasing trend for *P. clypeatus*. This was tested by applying Spearman's rank correlation between TFactor and year: *E. tenax* All records *rho* = 0.648 (95% confidence interval: 0.418–0.799), Excluding photographs *rho* = 0.579 (0.193–0.690); *P. clypeatus* All records *rho* = 0.758 (−0.582– −0.867), Excluding photographs *rho* = −0.568 (−0.310– −0.7.50). When the confidence intervals of *rho* do not include zero, if it was positive as in the case of *E. tenax*, we conclude that there has been a significant increase in the relative frequency with which the species was observed over time and if *rho* is negative (e.g., *P. clypeatus*), then a significant decrease, otherwise, if the confidence intervals included zero, we must conclude there has been no significant change.

The increasing number of photographic records received in recent years, mostly of large, colourful and flower visiting species such as *E. tenax*, has increased the proportion of records of such species in the dataset. But more cryptic, small and less obvious species like *P. clypeatus* are less likely to be photographed, and the proportion of their records in the dataset has decreased. This "photographic bias" causes the relative frequency with which they are observed to be overestimated in the former case and underestimated in the latter, as demonstrated in Figure 3. To test this bias, we performed a chi-squared test on the data for the two example species as set out in Table 1. This test confirms significant deviation from the expected abundance (*Eristalis tenax* p = 7.6E-124; *Platycheirus clypeatus* p = 1.4E-134) and shows how this deviation increases as the dominance of photographic records increases.

Table 1. Chi-squared test for records of *Eristalis tenax* and *Platycheirus clypeatus* over eight five-year epochs between 1980 and 2019.

	Total			*Eristalis tenax*				*Platycheirus clypeatus*			
Year	non-photo	photo	pro-portion	non-photo	photo	expected	Chi-sq	non-photo	photo	expected	Chi-sq
1980–84	56,139	17	0.0003	1,504	0	0.46	0.46	892	0	0.27	0.27
1985–89	124,994	7	0.0001	3,192	0	0.18	0.18	1,690	0	0.09	0.09
1990–94	103,198	11	0.0001	3,388	0	0.36	0.36	1,415	0	0.15	0.15
1995–99	80,391	51	0.0006	3,368	0	2.14	2.14	1,015	0	0.64	0.64
2000–04	89,082	383	0.0043	3,426	16	14.74	0.11	1,119	1	4.79	3.00
2005–09	94,537	5,265	0.0528	4,148	339	236.71	44.20	1,122	2	59.30	55.36
2010–14	115,690	27,277	0.1908	5,020	1,966	1,332.87	300.74	1,565	9	300.31	282.58
2015–19	99,800	110,387	0.5252	4,818	8,037	6,751.25	244.87	750	71	431.18	300.87
						Chi-sq. = 593.05 p = 7.6472E-124				Chi-sq. = 642.97 p = 1.4E-134	

Table 2 presents the impact on the assessment of trends. Comparing the two FRESCALO analyses, excluding photographic and electronic records changed the nature of the trend detected for 42 out of 237 species (17.8%) (Table 2). The main change was in species that were "decreasing" according to the "All records" analysis, but registered "no change" (22 species) (i.e., a swing of 9%) when photographic records were excluded, whilst only five switched from "no change" to "decreasing" (i.e., a reverse swing of 2%). In the increasing direction, the impact was smaller with nine switching from "no change" to "increasing" (i.e., a swing of nearly 4%), whilst six moved in the opposite direction (i.e., a swing of 2.5%). The overall impact was that excluding the electronic and photographic records decreased the proportion of species detected as "decreasing" (from 119 to 102 i.e., from 50 to 43%) and slightly raised the number of "increasing" species (from 35 to 38) and, of course, raised the number of species with the status "no change" from 83 to 97.

As might be expected, the differences lie primarily amongst species that are relatively widespread but at the more difficult end of the identification scale. Where species are difficult to identify from photographs, they are only recorded at generic level at best and are not included in the analysis; they therefore become 'invisible' to the sampling technique. Consequently, there is artificial under-representation within the dataset.

Table 2. Comparison of the number of species showing significant increase, significant decrease or no significant change between the two FRESCALO analyses.

		Excluding photographs			
		Decreasing	No change	Increasing	Total
All records	Decreasing	97	22	0	119
	No change	5	69	9	83
	Increasing	0	6	29	35
	Total	102	97	38	237

Discussion – Implications and Application

Effects on FRESCALO outputs

In this analysis we have demonstrated that outputs of the FRESCALO occupancy model can be significantly affected by changing the composition of the dataset as illustrated in Table 1. As far as we are aware, this is the first analysis to have demonstrated the possible impact of changes in recorder techniques on occupancy model outputs. Imperfect detection, as described by Kellner & Swihart (2014), was always present within opportunistic datasets for taxonomically challenging organisms prior to digital photography, but in the past ten years it has clearly increased with species that cannot be identified from photographs. Given the increasing tendency to report the most obvious species, there is a case for describing the developing process as 'selective detection' rather than 'imperfect detection'. It therefore follows that whilst FRESCALO may have accommodated traditional recorder bias, it is not robust enough to overcome species invisibility induced by a change in sampling technique.

More advanced models may overcome the complications we have identified, but until they are tested in detail there can be no guarantee that similar problems will not emerge. These models will need to incorporate weighting to take account of significant biases introduced by recording technique. As such, there will be an increasing need for data compilers to make sure that records have much more refined information on the recording techniques employed. At the moment data capture systems such as *iRecord* (iRecord 2021) do not make it obligatory to state how a determination was made i.e., was it based simply upon a visual appraisal, use of a net and hand lens, from a photograph or from lethal methods and microscopic examination? This problem is compounded in simpler 'apps' such as *iNaturalist* (*iNaturalist*, 2021), that offer simplicity of data entry as a benefit to the user, but leave the analyst with no means of determining the composition of the dataset.

This issue means that there is also a need to consider how data are generated and recorded in datasets so that possible recording anomalies can be taken into consideration. Whilst Recorder (the software we use) has fields specifically designed to flag the method by which records were made, and we ensure that the data we upload are flagged correctly to the best of our knowledge, we cannot always take account of the numerous recorders who submit their records as spreadsheets or as lists on *iRecord* and may not include this information. Computational methods of separating recorder behaviour into separate classes may need to be developed so that data can be interrogated independently or as co-variates within models.

Other pollinator groups such as the solitary bees and many other fly families also range from species that are easily identified and relatively widespread, to equally widespread but taxonomically difficult. It is therefore likely that a similar situation will obtain for them too.

These results also serve as a warning that data from highly heterogeneous sources may lead to headline-grabbing results that are not what it may seem. For example, Zattara & Aizen (2021) provide a graph for the numbers of bee species recorded that has very similar characteristics to the extreme trend we provide here for *Platycheirus clypeatus* (Fig. 3). We suspect that a decline in recording effort combined with small sample sizes are the dominant drivers of the trend they have described. If this is the case, the alarming headline is not the decline in the numbers of bee species but the weakness in the developing dataset and the risk that important and real trends will not be detected before it is too late to take action.

Implications for use of photographic data

It will not be possible for trends to be produced from photographic recording alone, for at least another five years. In the longer-term, however, the sheer volume of such records should allow some trends to be generated, although they will not cover the full spectrum of taxa (see Morris, 2020). Such trends will need to be presented carefully and with clear recognition that the data are a sub-set of the total fauna; as such they may serve as a warning of developing issues but the magnitude of the issues cannot be determined without a more comprehensive dataset.

Nevertheless, photographic recording does allow greater public participation in the science and will generate data that can be put to a variety of valuable uses. This shortfall in comprehensive data emphasises the importance of collected by traditional taxonomists who retain specimens and examine them in detail before producing their species lists. In Britain, these data are primarily supplied by an ageing (and declining) cohort of alpha-taxonomists; a conundrum that raises the question of how sufficiently robust data will be gathered in the face of declining numbers of competent taxonomists (Drew, 2011)?

Implications for biodiversity monitoring

Our results pose a challenge to organisations that have hitherto relied on opportunistic data to generate biodiversity trends. Headline results may not always be quite what they appear to be, as has been demonstrated by Zattara & Aizen (2021) whose results could be interpreted in two ways: in one it might be inferred that there has been a serious decline in the numbers of bee species; whilst an alternative interpretation of the results, drawing on our findings, suggests that the most serious immediate issue is the lack of systematic and comprehensive data collection!

Whilst there is clearly a need for more structured monitoring programmes for invertebrates, NGOs, Governments and analysts need to think about ways in which opportunistic datasets can be made more ‘fit for purpose’. Developing new ways to compartmentalise data is one possibility. Data capture systems also need to ensure that more attention is paid to the ways in which species determinations have been made (by making the field obligatory). Moreover, concerted efforts are needed to highlight the importance of sound taxonomic principles in data collection and the dangers that ongoing dilution of existing technical capacity will weaken datasets still-further.

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