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Occupancy modelling as a new approach to assess supranational trends using opportunistic data: a pilot study for the damselfly *Calopteryx splendens*

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Abstract There is limited information available on changes in biodiversity at the European scale, because there is a lack of data from standardised monitoring for most species groups. However, a great number of observations made without a standardised field protocol is available in many countries for many species. Such opportunistic data offer an alternative source of information, but unfortunately such data suffer from non-standardised observation effort and geographical bias. Here we describe a new approach to compiling supranational trends using opportunistic data which adjusts for these two major imperfections. The non-standardised observation effort is dealt with by occupancy modelling, and the unequal geographical distribution of sites by a weighting procedure. The damselfly *Calopteryx splendens* was chosen as our test species. The data were collected from five countries (Ireland, Great Britain, the Netherlands, Belgium and France), covering the

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period 1990–2008. We used occupancy models to estimate the annual number of occupied 1×1 km sites per country. Occupancy models use presence-absence data, account for imperfect detection of species, and thereby correct for between-year variability in observation effort. The occupancy models were run per country in a Bayesian mode of inference using JAGS. The occupancy estimates per country were then aggregated to assess the supranational trend in the number of occupied 1×1 km^2. To adjust for the unequal geographical distribution of surveyed sites, we weighted the countries according to the number of sites surveyed and the range of the species per country. The distribution of *C. splendens* has increased significantly in the combined five countries. Our trial demonstrated that a supranational trend in distribution can be derived from opportunistic data, while adjusting for observation effort and geographical bias. This opens new perspectives for international monitoring of biodiversity.

Keywords Detection · Monitoring · Distribution · Citizen science data · Odonata · JAGS

Introduction

Biodiversity is in decline worldwide (Butchart et al. 2010) and this had led to a growing concern for wildlife. Recently, the European Union launched a strategy aimed to halt biodiversity loss in the EU and restore it as far as feasible by 2020 (European Union 2011). In order to assess whether this target will be met, monitoring data are required on the status of many species, preferably at the European scale. However, data from standardised monitoring yielding information on European trends are scarce. Such information is currently mainly available for birds, some butterflies and some mammal species (de Heer et al. 2005; Gregory et al. 2005; European Environmental Agency 2007; van Swaay et al. 2008). For these species annual supranational population indices are available with confidence intervals allowing the statistical testing of trends. For birds and butterflies these species trends are combined into biodiversity indicators (European Environmental Agency 2007).

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It seems hardly feasible to collect standardised monitoring data on a large spatial scale for other species groups. Yet, in many countries a great number of opportunistic records is available, i.e., observations collected without standardised field protocol and without a design ensuring the geographical representativeness of sampled sites. The opportunistic records are single records for particular species and day-lists of species, i.e., records of multiple species collected by a single observer on one site and date. In recent years, the number of opportunistic records has increased greatly, with data entry facilitated through internet portals (e.g. waarneming.nl and observado.org). These data, often labelled as citizen science data, are a potentially valuable source of information on changes in biodiversity (Schmeller et al. 2009; Devictor et al. 2010). However, these data should be used with caution because the non-standardised observation efforts and the often uneven geographical distribution of records make national trend assessments unreliable (Dennis et al. 1999; Dennis and Thomas 2000; Robertson et al. 2010; Szabo et al. 2010; Hassall 2012). It is even more challenging to assess supranational trends from such opportunistic data, because the imperfections in the data may differ between countries.

In recent years, dynamic occupancy models (MacKenzie et al. 2006; Royle and Kéry 2007) have been proposed to derive reliable trend information from opportunistic data (Kéry et al. 2010; van Strien et al. 2010, 2011). Occupancy models use presence-absence data and yield estimates of the percentage of occupied sites (occupancy), e.g. $1 \times 1 \text{ km}^2$, per year. These models take into account the imperfect detection of species and this characteristic makes them useful for analyzing opportunistic data. The basic idea to analyse opportunistic data is that, all else being equal, greater observation effort increases the probability of detecting a species, so variation in observation effort over the years can be translated into variation in species detectability (Kéry et al. 2010). Using such models, Van Strien et al. (2010) demonstrated that in the Netherlands the trends for seven dragonfly species derived from opportunistic records during 1999–2007 were similar to trends derived from standardised monitoring data.

To the best of our knowledge, no attempts have so far been made to assess supranational trends from opportunistic data using occupancy modelling. The aim of this study is to explore whether a supranational trend for dragonflies could be generated from opportunistic data while adjusting for the imperfections mentioned. Several European countries have databases with many opportunistic records of dragonflies. We used records of dragonflies from Ireland, Great Britain, the Netherlands, Belgium and France. As a test species we chose *Calopteryx splendens*, which is a widespread species in all five countries.

Materials and methods

Data

All records used in this study were from adult dragonflies only. Data from Ireland include Northern Ireland and were obtained from the DragonflyIreland dataset managed by the Centre for Environmental Data and Recording (Northern Ireland) with the support of the National Biodiversity Data Centre (Republic of Ireland). Records collected are largely opportunistic and were submitted via email and websites. Data from Great Britain were obtained from the Dragonfly Recording Network of the British Dragonfly Society. Most records are opportunistic and verified by the national network of Vice County Recorders. The opportunistic data from the Netherlands were obtained from the National Database Flora and Fauna, maintained by the National Authority for Data concerning Nature. These

data are owned by the Dutch Society for Dragonfly Studies, Dutch Butterfly Conservation, and the European Invertebrate Survey—the Netherlands. Most records are currently collected through the internet portals waarneming.nl and telmee.nl. Data from the Dutch Dragonfly Monitoring Scheme were excluded because these were based on standardised field work. Dragonfly data from Belgium are collected by the Flemish Dragonfly Society and the Walloon Dragonfly Working Group and through the internet portals waarnemingen.be and observations.be which are managed by Natuurpunt and Natagora. Data from France came from the database managed by the French Society of Odonatology (SFO). The French data have been collected within the framework of the Odonata's national surveys, called INVOD (1980–2004) and CILIF (from 2004 onwards) (Dommanget 2002, 2010).

All data in each country were validated by experts to prevent false positive records. As *C. splendens* is easy to identify, false positive records are very unlikely. Data were restricted to 1990–2008, because each of the participating countries had data available in these years. The total amount of dragonfly data in the five countries has increased considerably since 1990 (Fig. 1). Not only has the amount of single records increased, but also of records of multiple species collected by a single observer at a single site on a single date.

Different geo-reference systems were used in each country for the observations. Hence, all observations were converted to the Universal Transverse Mercator (UTM) system. Because we used 1×1 km as the definition of a site in our analyses, all observations were referenced to 1×1 km UTM squares.

Generating non-detection data

Almost all data obtained were records of species presence. But occupancy models also require absence data, more precisely non-detection data, to estimate detection probabilities. Detection probability is estimated from the pattern in the detections and non-detections in replicated visits at sites. Valid replicated visits are only those visits made in a period of closure within the year; this is the period during which a site is considered to be either occupied or unoccupied and not abandoned or colonised (MacKenzie et al. 2006).

The non-detection records were generated from the information of sightings of other dragonfly species, following Van Strien et al. (2010, 2011). Any observation of *C.*
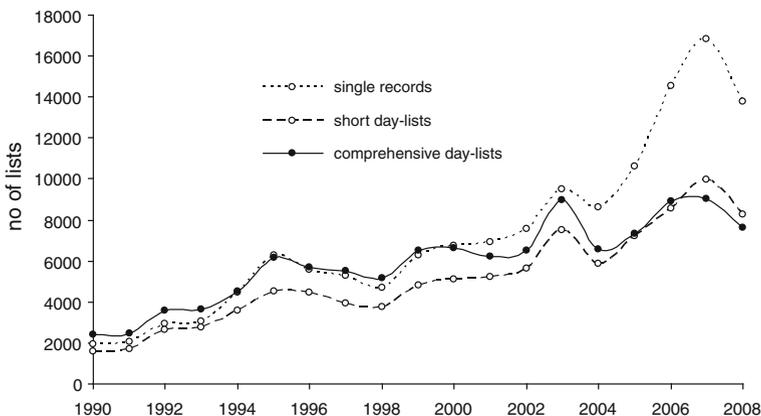
Fig. 1 Annual number of day-lists from five countries combined (Ireland, Great Britain, the Netherlands, Belgium and France). Lists were categorised as single records, short day-lists or comprehensive day-lists (see text for explanation). The dip in 2008 is due to a temporary dip in the number of data records in the Netherlands

splendens was taken as 1 (detection), whereas we rated 0 (non-detection) if any other species but not *C. splendens* had been reported by an observer at a particular 1 × 1 km site and on a particular date within the closure period. Usually, *C. splendens* is observed between Julian dates 130–250 and we used as closure period Julian dates 150–220. We made an exception for Ireland, where we used Julian dates 160–260 because the species seems to have a later flight period there. Despite many dragonflies having advanced their phenology in recent decades (Dingemans and Kalkman 2008), data exploration revealed no changes in flight period of our study species during 1990–2008, so the closure period was kept the same for all years.

Statistical analysis

National level

We applied the same dynamic occupancy model as Van Strien et al. (2010, 2011) to estimate annual occupancy ψ, adjusted for detection probability p. Because all parameters in the model may differ between countries, the analyses were performed separately for each country and the national results were combined in a second step. The mathematical description of the model is given by Royle and Kéry (2007) and Royle and Dorazio (2008). Here, ψ is the proportion of suitable 1 × 1 km^2 that is occupied. A square is defined as suitable if the species had been recorded there at least once in 1990–2008. The occupancy model consists of two hierarchically coupled submodels, one for occupancy and one for detection, the latter being conditional on the occupancy submodel. The occupancy sub-model estimates annual probability of persistence φ_t and of colonisation γ_t and computes the annual occupancy probability per site recursively through:

$$\psi_{it} = \psi_{i,t-1}\varphi_{t-1} + \left(1 - \psi_{i,t-1}\right)\gamma_{t-1}$$

Thus, whether site i occupied in year $t-1$ is still occupied in year t is determined by the persistence probability, and whether site i unoccupied in year $t-1$ is occupied in year t depends on the colonisation probability. All occupancy probabilities per site together yield the estimated annual number of occupied 1 × 1 km sites per country. The same sites were included in the analysis for all years; estimates for sites not surveyed during some years were derived from sites that were surveyed in those years.

The detection submodel estimates the detection per visit p, but in addition p is made a function of covariates. We used the Julian date as a covariate for p because the detection of the species is expected to vary over the season due to changing population size during the course of the flight period. Detection is also reduced if observers do not report all their sightings. Hence, we include the incompleteness of recording as a covariate for detection. We distinguished: (1) single records of any species on one site and date without records of other species, (2) short day-lists, i.e. records of two or three species made by a single observer on one site and date, and (3) comprehensive day-lists, i.e., records of more than three species per observer, site and date. These lists may or may not include *C. splendens*. These category thresholds are sufficiently low to be not confounded by real differences in species number between sites. In most 1 × 1 km sites in the countries there are more than three species to be found and often many more. Effects of both covariates were included in the detection submodel via a logit link:

$$\log \mathrm{it}\left(p_{ijt}\right) = \alpha_t + \beta_1 * \mathrm{date}_{ijt} + \beta_2 * \mathrm{date}_{ijt}^2 + \delta_1 * (\text{short day-list})_{ijt} + \delta_2$$
$$* (\text{comprehensive day-list})_{ijt},$$

where p_{ijt} is the probability to detect the species at site i during visit j in year t, α_t is the annual intercept, β_1 and β_2 are the linear and quadratic effects of the date of visit j and δ_1 and δ_2 are the effects of short day-lists and comprehensive day-lists, relative to single records.

We fitted the models in a Bayesian mode of inference using JAGS (Plummer 2009) on the computer cluster LISA (https://subtrac.sara.nl), with essentially the same WinBUGS code (Spiegelhalter et al. 2003) as given by Royle and Dorazio (2008; p. 309), but in addition we estimated the intercept α_t as a random year effect. We chose uninformative priors for all parameters, using uniform distributions with values between 0 and 1 for all parameters except δ_1 and δ_2 (values between -10 and 10), β_1, β_2 (values between -5 and 5) and α_t (values between 0 and 5 for the standard deviation of the normal distribution used as prior for the random year effect; see Kéry (2010) for examples of WinBUGS code for random effects).

For each analysis, we ran three Markov chains with 15,000 iterations to ensure convergence as judged from the Gelman-Rubin Rhat statistic. We discarded the first 10,000 iterations as burn-in and used the remaining iterations for inferences. Model fits were assessed using Bayesian p-values. This value is near 0.5 for a fitting model and values close to 0 or to 1 indicate inadequate fits (Kéry 2010). Our p-values varied between 0.44 and 0.59, suggesting that model fits were adequate. The model produced annual estimates of occupancy, persistence and colonisation per country and their regression coefficients across years were estimated as derived parameters (Kéry 2010).

Supranational level

The occupancy estimates per country were aggregated in the second step. Countries differ in the number of sites surveyed, so a naive aggregation has the risk of a biased supranational trend. Hence, we developed a procedure to weigh countries according to the sampling intensity in relation to the range of *C. splendens* in each country. This procedure is an adaptation of procedures applied by Van Swaay et al. (2002) and Gregory et al. (2005). The range of *C. splendens* in a country is defined as the number of 10×10 km^2 where the species has been observed at least once during 1990–2008. We assumed that these ranges are well known, which seems reasonable given the distribution of records (Fig. 2a). Sampling intensity is defined as the number of 1×1 km^2 surveyed at least once in this period within the range of the species. If sampling intensity would be even across countries, the number of surveyed 1×1 km^2 is proportional to the range of the species. So, if the range in one country is twice as large as in another country, twice as many 1×1 km^2 should have been surveyed to ensure even sampling. When the share of 1×1 km^2 surveyed is higher than proportional, the country is considered oversampled. Weights are calculated as the quotient of relative range and relative sampling intensity, to compensate for oversampling and undersampling (Table 1). Weights per country were similar for each year, because the same sites were in the analysis for all years. The weighted numbers of occupied sites were added across countries and converted into supranational annual occupancy. Similarly, standard errors of national occupancies were combined to achieve standard errors of the supranational annual occupancy.
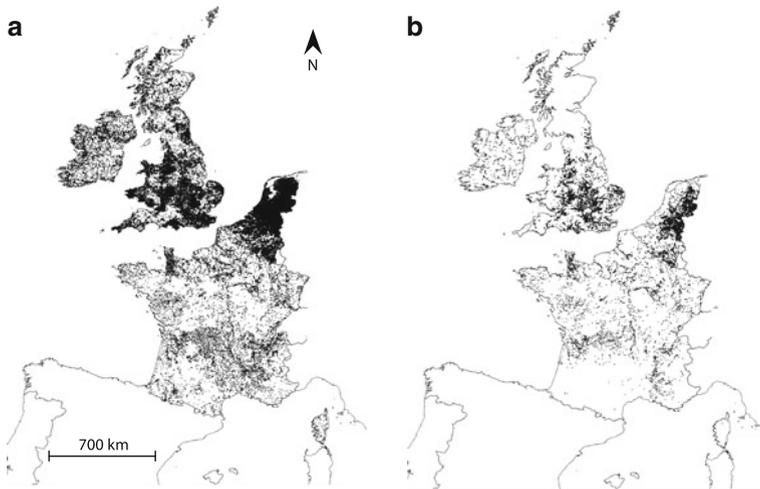
Fig. 2 Map of 1 × 1 km sites with **a** opportunistic records of dragonflies in 1990–2008 and **b** sites where *Calopteryx splendens* has been observed in the same period

Table 1 Ingredients to treat relative oversampling and undersampling of countries with respect to *Calopteryx splendens*

Country	Range (10 × 10 km^2 with *C. splendens*)	Sampling intensity (1 × 1 km^2 surveyed within range of *C. splendens*)	Weight (% range/% sampling intensity)
Ireland	276 (7.8 %)	1,768 (4.2 %)	1.86
Great Britain	962 (27.4 %)	15,513 (36.6 %)	0.74
The Netherlands	317 (9.0 %)	15,798 (37.3 %)	0.24
Belgium	230 (6.6 %)	3,987 (9.4 %)	0.70
France	1,725 (49.1 %)	5,275 (12.4 %)	3.96

Results

In each nation, opportunistic records came from all over the country, although some areas were overrepresented, e.g. the southern half of England, and the Netherlands and Belgium as a whole (Fig. 2a). Great Britain and the Netherlands had relatively large shares of single records in their data, at least for those sites where *C. splendens* occurs (Table 2). The share of single records was even greater (46.8 %) in Ireland. In contrast, databases in France and Belgium held more comprehensive and short lists than single records.

Calopteryx splendens is absent in Scotland and south-western France (Fig. 2b); in the latter region the species is replaced by the related *C. xanthostoma*. Occupancy has significantly increased in Great Britain, the Netherlands and Belgium and remained stable in France (Fig. 3; Table 3). In Ireland, the standard errors of the annual occupancy estimates were considerable, except for 1996–2003 when more data were available. As a result, the trend in occupancy is poorly known for Ireland (Table 3). In none of the countries persistence and colonisation has changed significantly over the years (Table 3),

Table 2 Number of day-lists per country and day-list category in 1990–2008 in 1×1 km^2 where *Calopteryx splendens* has been observed at least once

Country	Single records data (%)	Short day-lists (%)	Comprehensive day-lists (%)
Ireland	372 (46.8)	223 (28.0)	200 (25.1)
Great Britain	9,543 (30.7)	7,926 (25.5)	13,636 (43.8)
The Netherlands	9,850 (34.9)	7,005 (24.8)	11,378 (40.3)
Belgium	1,391 (23.0)	1,404 (23.2)	3,261 (53.8)
France	1,294 (13.5)	1,642 (17.1)	6,664 (69.4)

When the results of all five countries were combined, the species showed a significant increase in occupancy (weighted trend 0.004 with standard error 0.001; $p < 0.05$; Fig. 4). Because the stable trajectory in France had more influence in the weighted trend, the unweighted trend is slightly steeper (0.006 with standard error 0.001) than the weighted trend, although the difference in trend is not significant. Weights for France were highest and for the Netherlands lowest, reflecting their respective undersampling and oversampling (Table 1).

In almost all countries, detection probabilities varied significantly with Julian date. Detection peaks did not differ much between countries and were around Julian date 170, except for Ireland. As expected, in most countries detection in short day-lists and comprehensive day-lists was significantly higher than in single records data (Table 4). The opposite was true in Ireland, with exceptionally high detections in single records and short day-lists (Table 4). There was no indication of a trend in detection during 1990–2008 in any of the countries.

Discussion

We have described a new approach to compose supranational trends using opportunistic data. The approach takes into account the two main imperfections in opportunistic data. The non-standardised observation effort is dealt with by occupancy modelling and the unequal geographical distribution of sites by a weighting procedure.

In monitoring schemes variation in observation effort is minimized by adopting a standard field methodology, e.g. reporting all species detected at a site and adhering to a particular field method and timing of visits to a site. In contrast, variation in observation effort is substantial in opportunistic data. Many attempts have been made to extract trend information from opportunistic data, e.g. by comparing only sites that had been equally surveyed (see Hassall and Thompson 2010) or by a statistical correction method with a proxy for observation effort (Szabo et al. 2010). Occupancy models provide a more general method to control observation effort by assuming that variation in observation effort will result in a different detection probability of species, whatever its source may be. So, the variation in number and timing of field visits, variation in field efforts during a visit and variation in observer skills and in their readiness to report a species after detection are all assumed to be reflected in variation in detection. We adjusted for these sources of variation by taking into account detection probability in an occupancy model and we also included day-list category and Julian date as a covariate for detection.

Our trial of the new approach showed an increase of *C. splendens* which agrees well with expert knowledge of the species. As a direct cross-check for the trend in the
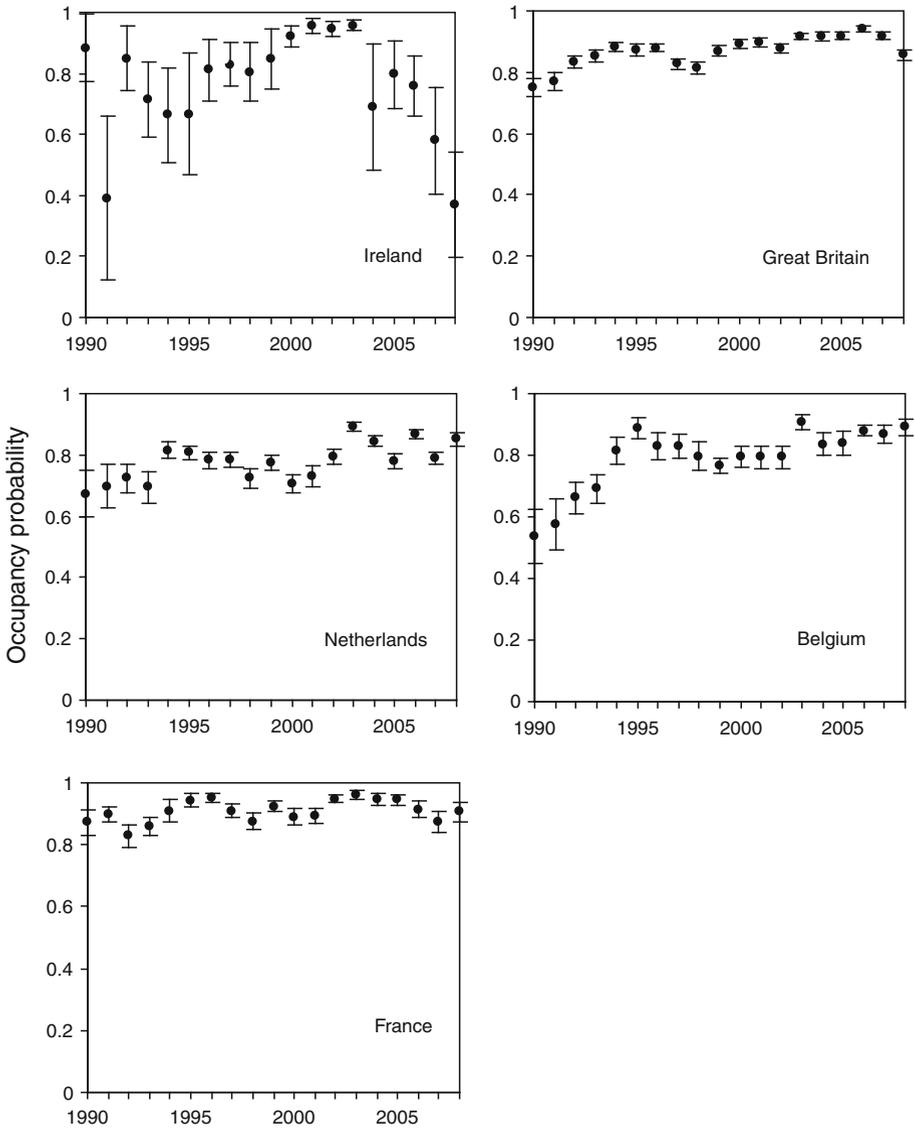
Fig. 3 Annual occupancy probability (±se) of *Calopteryx splendens* in Ireland, Great Britain, the Netherlands, Belgium and France, analysed with a dynamic occupancy model

Netherlands, we used independent monitoring data available for the Netherlands. We selected a subset of squares ($n = 105$) from which both opportunistic data and monitoring data were available and found a similar trend in occupancy in 1999–2010 (trend ± se -0.005 ± 0.006 and -0.004 ± 0.006 respectively). This confirms our earlier findings that opportunistic data may produce reliable trends if analysed by an occupancy model (Van Strien et al. 2010). Note that the decline found in the data used for comparison contradicts the overall trend found for the Netherlands. This is because the subset of squares was not representative for the whole country.

Table 3 Trend in occupancy, colonisation and persistence (±se) of *Calopteryx splendens* per country in 1990–2008

Country (no. of sites)	Trend in occupancy	Trend in colonisation	Trend in persistence
Ireland (409)	−0.002 ± 0.006	−0.001 ± 0.012	0.001 ± 0.011
Great Britain (4,954)	0.007 ± 0.001[a]	0.004 ± 0.003	0.001 ± 0.001
The Netherlands (3,294)	0.007 ± 0.002[a]	0.005 ± 0.006	0.003 ± 0.002
Belgium (1,200)	0.014 ± 0.003[a]	0.003 ± 0.004	0.005 ± 0.003
France (2,666)	0.002 ± 0.002	0.000 ± 0.008	0.001 ± 0.001

No. of sites refers to the 1×1 km^2 where *C. splendens* has been observed at least once

[a] Significant ($p < 0.05$)
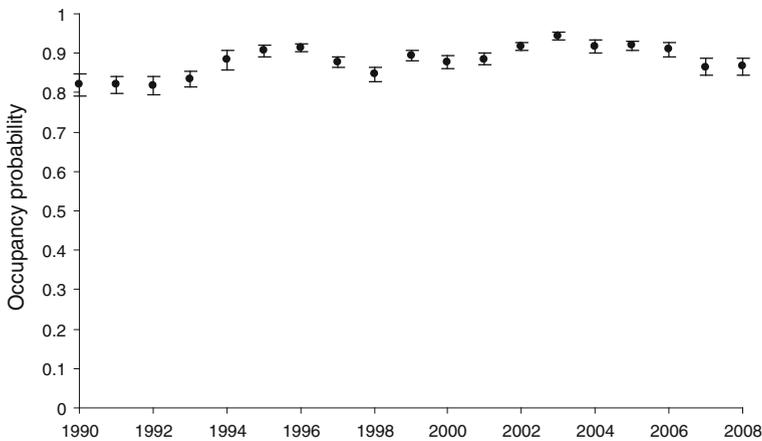
Fig. 4 Annual occupancy probability (±se) of *Calopteryx splendens* in five countries combined after countries were given different weights to adjust for different sampling intensity

Table 4 Detection probability of *Calopteryx splendens* (±se) per country and day-list category

Country (no. of sites)	Single records data	Short day-lists	Comprehensive day-lists
Ireland	0.83 ± 0.06	0.75 ± 0.09	0.65 ± 0.10[a]
Great Britain	0.44 ± 0.03	0.55 ± 0.03[a]	0.62 ± 0.02[a]
The Netherlands	0.38 ± 0.03	0.40 ± 0.03	0.50 ± 0.03[a]
Belgium	0.45 ± 0.04	0.56 ± 0.04[a]	0.61 ± 0.04[a]
France	0.19 ± 0.02	0.44 ± 0.03[a]	0.68 ± 0.03[a]

[a] Significant difference with detection in single records data ($p < 0.05$)

Sites from which we had opportunistic records were not selected by using a formal sampling design, but instead by the free choice of observers. This might lead to an unequal geographical distribution of sites and to biased results within countries (Yoccoz et al. 2001; Hassall 2012). We have ignored this potential bias, because we identified no clear skewed geographical distribution within countries (Fig. 2a). An exception is Great Britain, where England has a higher density of surveyed sites than Scotland. However, this is not relevant

in our case because *C. splendens* does not occur in Scotland (Fig. 2b). Where apparent geographical bias at the national level exists, this could be treated by a post-stratification of sites, e.g. by using regions or habitat types as strata, followed by weighting of strata (van Swaay et al. 2002; Gregory et al. 2005), much as we did to calculate trends at the supranational level.

Like other dragonflies living in running water, our study species suffered considerably during 1950–1980 from water pollution, deterioration of aquatic vegetation and physical alterations to water bodies. Improvements in these conditions have led to local recovery (Ward and Mill 2004; De Knijf et al. 2006) and here we show that the species has increased on a large spatial scale as well. The lack of any change in France hides a disparity: in several catchments the quality of running waters has improved during the two last decades (Service de l'observation et des statistiques 2010), but in some other catchments water quality has not much or not at all improved (Service de l'observation et des statistiques 2009). In addition, the species has expanded its range northwards in the UK, probably as the result of a combination of the effects of climate change (Hickling et al. 2005) and of improved water quality of rivers and streams in the northern part of the UK, which acted as a barrier to range expansion due to historic water pollution (Ward and Mill 2004).

Model assumptions

Some additional assumptions which may invalidate our results need to be addressed. First, in the occupancy modelling, we have assumed a period in the season during which no colonisation or extinction of the study species in sites happened. But dragonflies may disperse during the entire season. A lack of closure may lead to low estimates of detection probability and to positive bias in the occupancy estimate (Rota et al. 2009). This is a problem in case occupancy is taken to mean 'permanent presence'. But if random movement occurs to and from sites that are not permanently occupied, as we believe to be the case with mobile organisms like dragonflies, the occupancy parameter should be interpreted as the proportion of sites "used" by the target species during the period over which closure is assumed (MacKenzie et al. 2006).

Secondly, we assumed that sightings of other species were informative about a non-detection of our study species. Some observers might have surveyed running waters in the $1 \times 1 \text{ km}^2$, which are possibly inhabited by *C. splendens*, so any detection of another species is indeed informative about a non-detection of *C. splendens*. Others, however, might have surveyed only fens or ditches or other habitats unsuitable for *C. splendens*. In the latter habitat types, the detection of other species is not informative about the detection probability of *C. splendens*. Nevertheless, we expect that this sampling behaviour does not lead to biased occupancy estimates. Kendall and White (2009) demonstrated that sampling of spatial subunits without replacement in a site leads to bias in occupancy estimates, but not sampling with replacement. We consider the collection of opportunistic data by many observers comparable to sampling with replacement, leading to a decent quality of our estimates.

Thirdly, our procedure to generate non-detections for our study species from sighting of other species will not work in practice if there are only a few species in a site or only rare species. Then day-lists will often have length zero, but such informative non-detections rarely enter the databases. In such situations, many records are presences of the study species leading to unlikely high detection estimates. This happens in Ireland, which is naturally poor in dragonfly species and where *C. splendens* is often found on its own (Kalkman et al. 2010; Nelson et al. 2011). Single records data form the largest group of

records here (Table 2) and detection probability is exceptionally high (Table 4). To a lesser extent this is also true for short day-lists in Ireland. In such cases the mechanism to adjust for variation in observation effort via taking into account detection fails. Some form of standardised monitoring is probably the only option to achieve an unbiased trend estimate for this species in Ireland. Incidentally, any bias in the Irish data will hardly affect the supranational trend estimate, because Ireland contains only a limited share of this species anyway (Table 1).

Perspectives

Our trial demonstrated that supranational annual indices with confidence intervals and a supranational trend can be derived from opportunistic data, while adjusting for observation effort bias and geographical bias. The annual indices with confidence intervals allow the formal testing of trends. These characteristics make our approach superior to previous large-scale assessments of changes in species, such as for dragonflies by Clausnitzer et al. (2009).

Occupancy models, however, can only be applied if the data contain a sufficient number of replicated visits at sites within the season (MacKenzie et al. 2006). Outside Europe, the number of dragonfly records seems quite limited (see e.g. Hassall 2012), so the number of records from replicated visits might be too low for large-scale application of these models. But we suspect that over half of the EU member states currently have useful databases available with considerable amounts of opportunistic dragonfly records. Several other EU countries would be able to join with relatively little extra effort in data collection, for instance by focussing on the collection of records at a limited number of selected sites. This situation might be similar for some other insect groups in the EU, e.g. for grasshoppers, and is likely to be even better for butterflies. We envisage the growing databases of opportunistic data becoming an important source of information to track trends in multiple species groups. When owners of opportunistic data are prepared to cooperate in a Pan-European network, it should be feasible to achieve Pan-European trends in distribution for a number of species groups in the future. The usefulness of databases with opportunistic data can be further enhanced by encouraging the collection of day-lists rather than of single records (van Strien et al. 2010). However, trend information derived from opportunistic data will only be reliable if sufficient attention is given to using appropriate methods of analysis.

Our approach could make it possible to compile large-scale multispecies indicators, based on averaging annual indices per species. Such indicators resemble existing indicators for breeding birds and grassland butterflies (Gregory et al. 2005; European Environmental Agency 2007; van Swaay et al. 2008). But for dragonflies a supranational indicator would be based on changes in distribution rather than in population abundance as in the indicators for birds and butterflies. Finally, occupancy models enable to produce annual species distribution maps from opportunistic data (Kéry 2011; van Strien et al. 2011), which may facilitate large-scale studies on climate change, e.g. to compare range shifts of various species groups driven by climatic change (Devictor et al. 2012).

References

Butchart SHM, Walpole M, Collen B, van Strien A, Scharleman JPW et al (2010) Global biodiversity: indicators of recent declines. Science 328:1164–1168

Clausnitzer V, Kalkman VJ, Ram M, Collen B, Baillie JEM, Bedjanic M, Darwall WRT, Dijkstra KB, Dowf R, Hawking J, Karube H, Malikova E, Paulson D, Schutte K, Suhling F, Villanuevam RJ, von Ellenrieder N, Wilson K (2009) Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. Biol Conserv 142:1864–1869

De Heer M, Kapos V, ten Brink BJE (2005) Biodiversity trends in Europe: development and testing of a species trend indicator for evaluating progress towards the 2010 target. Philos Trans R Soc B 360:297–308

De Knijf G, Anselin A, Goffart P, Tailly M (eds) (2006) De libellen (Odonata) van België: verspreiding —evolutie—habitats [Dragonflies (Odonata) of Belgium: distribution—evolution—habitats]. Libellenwerkgroep Gomphus & Instituut voor Natuur- en Bosonderzoek, Brussel [Dutch with English abstract]

Dennis RLH, Thomas CD (2000) Bias in butterfly distribution maps: the influence of hot spots and recorders home range. J Insect Conserv 4:73–77

Dennis RLH, Sparks TH, Hardy BP (1999) Bias in butterfly distribution maps: the effect of sampling effort. J Insect Conserv 3:33–42

Devictor V, Whittaker RJ, Beltrame C (2010) Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. Divers Distrib 16:354–362

Devictor V, van Swaay C, Brereton T, Brotons L, Chamberlain D, Heliölä J, Herrando S, Julliard R, Kuussaari M, Lindström Å, Reif J, Roy DB, Schweiger O, Settele J, Stefanescu C, van Strien A, van Turnhout C, Vermouzek Z, WallisDeVries M, Wynhoff I, Jiguet F (2012) Differences in the climatic debts of birds and butterflies at a continental scale. Nat Clim Chang. doi:10.1038/nclimate1347:1-4

Dingemans N, Kalkman VJ (2008) Changing temperature regimes have advanced the phenology of Odonata in the Netherlands. Ecol Entomol 33:394–402

Dommanget JL (2002) Protocole de l'inventaire cartographique des Odonates de France (Programme INVOD). Muséum National d'Histoire Naturelle, Société française d'odonatologie, Paris

Dommanget JL (2010) Complément à l'inventaire des libellules de France (Programme national de collecte des données odonatologique (Programme CILIF), Actualisation janvier 2010. Société française d'odonatologie http://www.libellules.org/protocole/cilif.html/. Accessed 15 June 2012

European Environment Agency (2007) Halting the loss of biodiversity by 2010: proposal for a first set of indicators to monitor progress in Europe. EEA, Copenhagen

European Union (2011) Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM(2011) 244 final, Brussels

Gregory RD, van Strien A, Vorisek P, Gmelig Meyling AW, Noble DG, Foppen RPB, Gibbons DW (2005) Developing indicators for European birds. Philos Trans R Soc B 360:269–288

Hassall C (2012) Predicting the distributions of under-recorded Odonata using species distribution models. Insect Conserv Divers 5:192–201

Hassall C, Thompson DJ (2010) Accounting for recorder effort in the detection of range shifts from historical data. Methods Ecol Evol 1:343–350

Hickling R, Roy DB, Hill JK, Thomas CD (2005) A northward shift of range margins in British Odonata. Glob Chang Biol 11:502–506

Kalkman VJ, Boudot JP, Bernard R, Conze KJ, de Knijf G, Dyatlova E, Ferreira S, Jović M, Ott J, Riservato E, Sahlén G (2010) European red list of dragonflies. Publications Office of the European Union, Luxembourg

Kendall WL, White GC (2009) A cautionary note on substituting spatial subunits for repeated temporal sampling in studies of site occupancy. J Appl Ecol 46:1182–1188

Kéry M (2010) Introduction to WinBUGS for ecologists: a Bayesian approach to regression, ANOVA, mixed models and related analyses. Academic Press, Burlington

Kéry M (2011) Towards the modelling of true species distributions. J Biogeogr 38:617–618

Kéry M, Royle JA, Schmid H, Schaub M, Volet B, Häfliger G, Zbinden N (2010) Site-occupancy distribution modeling to correct population-trend estimates derived from opportunistic observations. Conserv Biol 24:1388–1397

MacKenzie DI, Nichols JD, Royle JA, Pollock KH, Hines JE, Bailey LL (2006) Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier, San Diego

Nelson B, Ronayne C, Thompson R (2011) Ireland Red List No. 6. Damselflies & Dragonflies (Odonata). National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin

Plummer M (2009) JAGS Version 1.0.3 manual. http://sourceforge.net/projects/mcmc-jags/. Accessed 15 June 2012

Robertson MP, Cumming GS, Erasmus BFN (2010) Getting the most out of atlas data. Divers Distrib 16:363–375

Rota CT, Fletcher RJ, Dorazio RM, Betts MG (2009) Occupancy estimation and the closure assumption. J Appl Ecol 46:1173–1181

Royle JA, Dorazio RM (2008) Hierarchical modeling and inference in ecology. Academic Press, Amsterdam

Royle JA, Kéry M (2007) A Bayesian state-space formulation of dynamic occupancy models. Ecol 88:1813–1823

Schmeller DS, Henry PY, Julliard R, Gruber B, Clobert J, Dziock F, Lengyel S, Nowicki P, Déri E, Budrys E, Kull T, Tali K, Bauch B, Settele J, van Swaay C, Kobler A, Babij V, Papastergiadou E, Henle K (2009) Advantages of volunteer-based biodiversity monitoring in Europe. Conserv Biol 23:307–316

Service de l'observation et des statistiques (2009) Évolution de la qualité des cours d'eau: volet macro-polluants. Études et documents, SOeS et Commissariat général au développement durable, Orléans

Service de l'observation et des statistiques (2010) L'environnement en France—edition 2010. Références, SOeS et Commissariat général au développement durable, Orléans

Spiegelhalter D, Thomas A, Best NG (2003) WinBUGS user manual, version 1.4. MCR Biostatistics Unit, Cambridge

Szabo JK, Vesk PA, Baxter PWJ, Possingham HP (2010) Regional avian species declines estimated from volunteer-collected long-term data using list length analysis. Ecol Appl 20:2157–2169

Van Strien AJ, Termaat T, Groenendijk D, Mensing V, Kéry M (2010) Site-occupancy models offer new opportunities for dragonfly monitoring based on daily species lists. Basic Appl Ecol 11:495–503

Van Strien AJ, van Swaay CAM, Kéry M (2011) Metapopulation dynamics in the butterfly *Hipparchia semele* changed decades before occupancy declined in The Netherlands. Ecol Appl 21:2510–2520

Van Swaay CAM, Plate CL, van Strien A (2002) Monitoring butterflies in the Netherlands: how to get unbiased indices. Proc Exper Appl Entomol NEV Amsterdam 13:21–27

Van Swaay CAM, Nowicki P, Settele J, van Strien AJ (2008) Butterfly monitoring in Europe: methods, applications. Biodivers Conserv 17:3455–3469

Ward L, Mill PJ (2004) Distribution of the Banded Demoiselle *Calopteryx splendens* (Harris) in northern England: an example of range expansion. J Br Dragonfly Soc 20:61–69

Yoccoz NG, Nichols JD, Boulinier T (2001) Monitoring of biodiversity in space and time. TREE 16:446–453