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SHORT COMMUNICATION

Calculating population reductions of invertebrate species for IUCN Red List assessments

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Abstract
Population reductions are often used to assess extinction risk of species in the IUCN Red List. Guidelines for Red List assessments describe specific methods for calculating the amount of reduction for species with strongly fluctuating populations. Recently, an alternative approach that involves expert opinion has been suggested for calculating population reduction in insect species. We argue that, while populations with high temporal variability do present challenges, the alternative suggestion is unnecessary, and inconsistent with the IUCN Red List Categories and Criteria.
Implications for insect conservation Consistent application of standardized methods for calculating population reductions allows robust and objective assessment of extinction risk faced by invertebrate species.

Keywords Threatened species · Red List · Population decline · Monitoring · Time series

Population reductions are a symptom of species endangerment, and are often used to assess species in the IUCN Red List. A recent paper (Fox et al. 2019) focused on the issue of calculating reduction for insect species with strongly fluctuating populations for use in the IUCN Red List assessments of these species, and proposed an approach as an alternative to the methods described in the Red List Guidelines (IUCN Standards and Petitions Committee 2019). Specifically, they took issue with the 10-year window for assessing extinction risk and proposed using the available time series together with expert opinion. In this note, we argue that, although the concerns of Fox et al. (2019) are valid, their recommendation is unnecessary, as well as inconsistent with the IUCN Red List Categories and Criteria.

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Population reductions are used in IUCN Red List criteria A and C, and are scaled to generation length (IUCN 2012). Here, for simplicity, we focus on past reduction under criterion A2, for a species with a short generation length such that reduction is calculated over a 10-year period (different considerations apply to species with long generation times, and for projecting future reductions). When census data include large fluctuations from year to year, calculating past reduction based on the ratio of current population size to the population size 10 years ago may result in large variation in the calculated reduction amount, which may vary substantially as a new population size estimate becomes available every year, as described by Fox et al. (2019). To reduce this variability, the Red List Guidelines (IUCN Standards and Petitions Committee 2019) prescribe fitting a model to the census data, and calculating the reduction based on the fitted values. When the available time series is longer than 10 years, the Guidelines prescribe fitting a decline model to the whole time series, and calculating reduction based on the fitted values of the last 10 years.

An important factor that determines how the reduction is calculated is the model that is fitted. The Red List Guidelines ask the assessors to fit a model that reflects the pattern of the decline, which may be exponential, linear, accelerated, or a more complex pattern, and which may be inferred from the type of threat, as detailed in the Red List Guidelines (IUCN Standards and Petitions Committee 2019; Sect. 4.5.1). The assumed pattern of decline can make an important difference to the calculated reduction. If the fitted model is exponential, then which 10-year period is used to calculate reduction is irrelevant. Exponential decline means that the annual rate of decline is the same for all years. So, 10-year reduction will be the same value regardless of which 10-year segment is analyzed, such as the last 10 years or the first 10 years (Fig. 1).

However, some threats result in changing rates of decline through time. The Red List Guidelines give examples of these. One example is a decline that is linear in population size. If a similar number of individuals are removed from the population every year, the decline will be linear in population size, which means the rate of decline will accelerate over time. This might happen, for instance, if the species is threatened with habitat loss, and a similar-sized area of habitat is lost every year. Sometimes even an increasing number of individuals may be lost every year (for instance, if the habitat area lost is increasing from year to year), resulting in even a larger acceleration in the decline rate.

When the annual decline rate is changing, it is important that the reduction is calculated from the last 10 years of the fitted model. Otherwise, the reduction may be underestimated (if the annual decline is accelerating). Figure 2 demonstrates this with a simple example, based on population change simulated by removing a fixed number of individuals from a randomly fluctuating population. In this case, the decline is linear in N (population size), and thus the annual rate of decline is accelerating. Over the first 10-year period, the average, model-fitted decline is less than 16%, and it increases to over 35% in the last 10-year period. In such cases where the annual rate of decline has a temporal trend, average annual rate of decline is meaningless and should not be used. Instead, the reduction in the last 10-year period should be used. Assessors must also consider future reduction, especially when decline rate is increasing or may increase, but this is outside the scope of this paper.

Another type of a changing rate of decline can happen after a one-time loss of habitat. Following a sudden

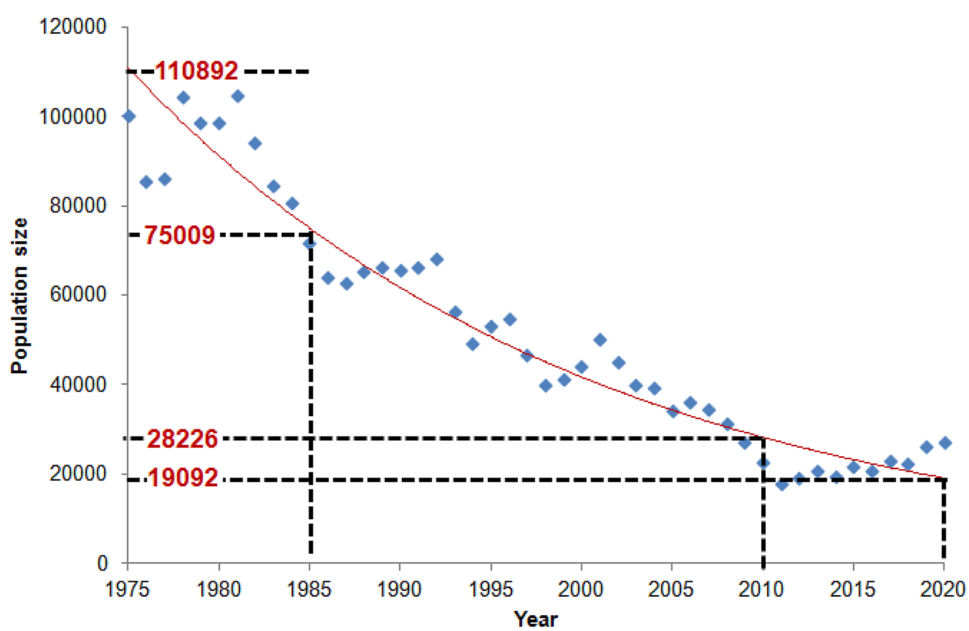

Fig. 1 Example of calculating reduction after fitting an exponential decline model to a 45-year time series of population sizes. The "data" (blue markers) are produced by a simple model of exponential decline with variability in annual rate of decline. An exponential decline curve (red) is fitted to these points. Reduction over a 10-year period is calculated as 32% based on any 10-year period, for example the last 10 years, 1 – (19,092/28,226), or the first 10 years, 1 – (75,009/110,892)

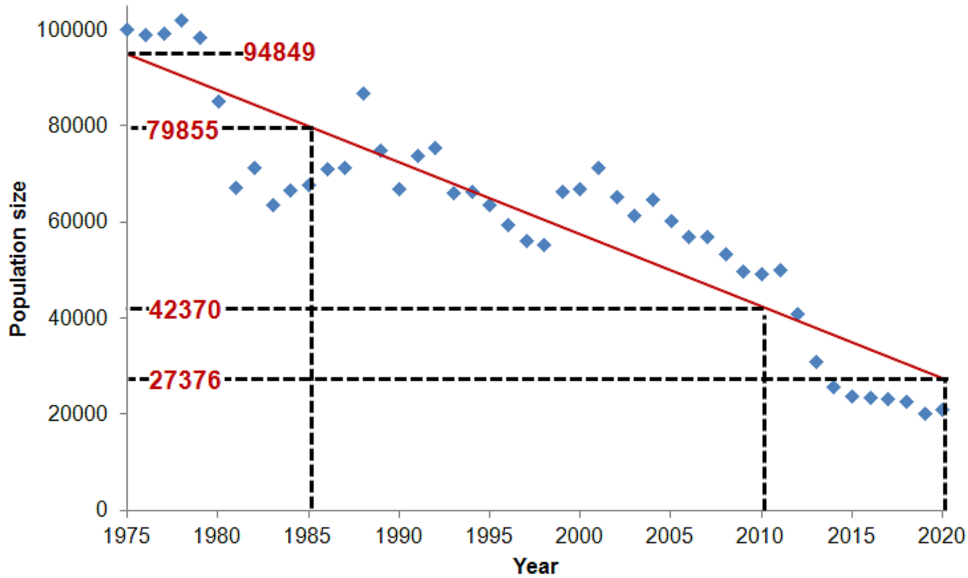

Fig. 2 Example of calculating reduction after fitting a linear decline (in N) to a 45-year time series of population sizes. The "data" (blue markers) are produced by a simple model of removing a fixed number of individuals from a randomly fluctuating population. A line (red) is fitted to these points. Reduction over a 10-year period depends on which 10-year period is used. In the first 10-year period, reduction is < 16% (1 – (79,855/94,849)), thus the Red List category would be incorrectly determined as LC, if the first 10-year period was mistakenly used. In the last 10-year period, reduction is > 35% (1 – (27,376/42,370)), thus the Red List category is VU

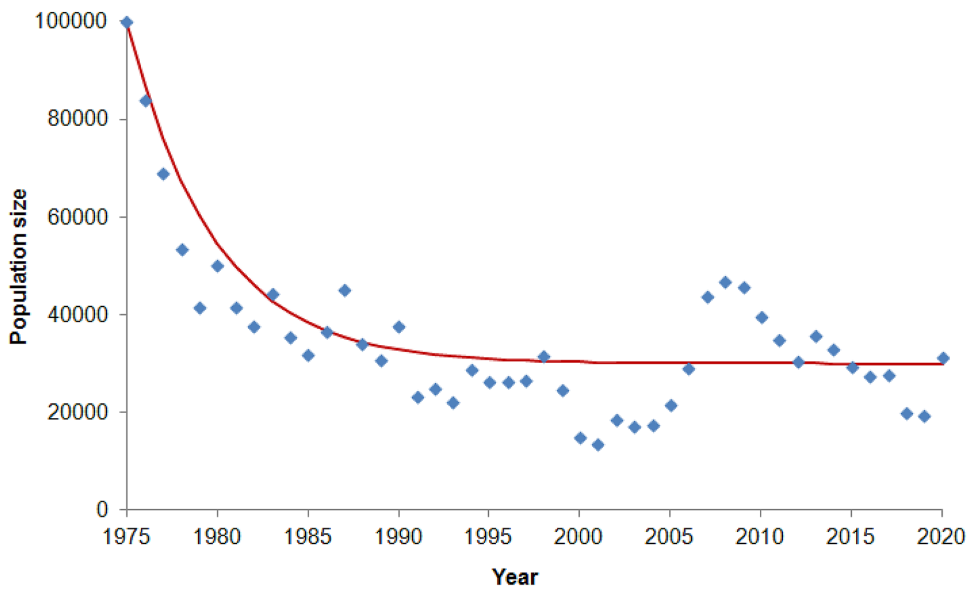

Fig. 3 Example of calculating reduction after fitting a model of logistic decline to a new and lower carrying capacity to a 45-year time series of population sizes. The "data" (blue markers) are produced by a stochastic logistic model with an initial abundance (100,000) that is above its carrying capacity (30,000). A line (red) is fitted to these points. Reduction over a 10-year period depends on which 10-year period is used. In the first 10-year period, reduction is > 60%, thus the Red List category would be incorrectly determined as EN, if the first 10-year period was mistakenly used. In the last 10-year period, reduction is < 1%, thus the Red List category is LC

reduction in habitat, the population would be above its carrying capacity, to which it might return in the long run, provided that the remaining habitat is constant in area and quality. Figure 3 demonstrates this with a simple example, based on population change simulated by a logistic model that starts with a population size far above the carrying capacity. Over the first 10-year period, the average, model-fitted decline is more than 60%, and it decreases to almost

0% in the last 10-year period. As in the previous case, average annual rate of decline is meaningless and should not be used. Instead, the reduction in the last 10-year period should be used.

Fox et al. (2019) recognize that IUCN guidelines address this issue, but consider the solution inadequate for several reasons. First they state that the guidance "is optional, dependent on the availability of long-term data and relies on practitioners being familiar with the detailed IUCN guidance." The availability of data longer than 10 years is indeed a requirement for fitting a data series longer than 10 years, so this requirement is unavoidable. The reliance on assessors being familiar with the guidance provided to them is also unavoidable, and would apply to any other suggestion as well, including those by Fox et al. (2019). Finally, dependence on data availability and assessor familiarity may make the guidance conditional, but would not make it optional. Fox et al. (2019) also claim that "high levels of inter-annual population variability within the 10-year period are still likely to strongly skew trends and therefore Red List assessments." As demonstrated above, if the population is declining exponentially, this is not an issue; and if it is declining in any other pattern, it is important to base the reduction on the last 10 years in order to accurately reflect the current risk levels.

Following the IUCN guidance reduces temporal variation of the Red List category. To demonstrate this, we analyzed one of the species that Fox et al. (2019) reported as having the most variable Red List category. The Clouded Yellow (*Colias croceus*) population has high temporal variability, and Fox et al. (2019) calculated its Red List category to be changing from Endangered (EN) to Critically endangered (CR), back to EN, and finally to Vulnerable (VU), within a 15-year period. However, if all the available data for this species (from UK Butterfly Monitoring Scheme; Botham et al. 2020) are analyzed according to the Red List guidelines, the species is assessed at the lowest extinction risk category of Least Concern (LC; Fig. 4).

However, Fox et al. (2019) are correct that if only a single ten-year segment of the data given in Fig. 4 had been available, a larger reduction could have been calculated. Of the 31 possible 10-year segments (from 1979–1988 to 2010–2019), 11 would have resulted in a reduction of 30% or more. Although this means that the reduction does depend on the years for which monitoring data are available, note that these 11 10-year segments with > 30% reduction are limited to only 2 periods: starting with 1979 to 1983, and 2000 to 2005 (Fox et al. 2019 focused on the second period). Both of these periods include multi-year declines (e.g., 5 years of continual decline starting in 1983), and a precautionary stance requires that "a reduction should not be interpreted as part of

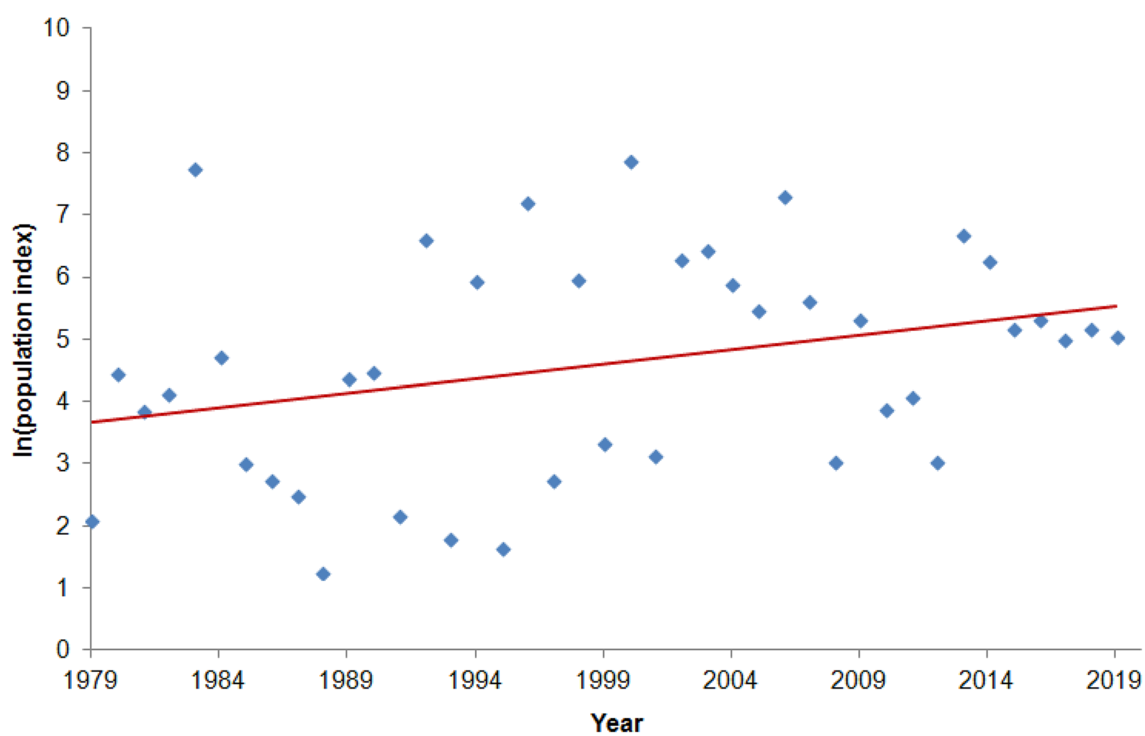

Fig. 4 Population index of Clouded Yellow (*Colias croceus*). Note the log scale of the vertical axis. The data (blue markers) are from UK Butterfly Monitoring Scheme (Botham et al. 2020). A line (red) is fitted to these points. Note that, because of the log scale, a linear fit implies an overall exponential population change (in this case, exponential growth over 4 decades)

a fluctuation unless there is good evidence for this" (IUCN 2012). The precautionary approach is especially important when reductions continue for multiple generations of the species. In this case (Fig. 4), even if only a single 10-year segment had been available, subsequent years of data would have indicated that the reduction was indeed part of a fluctuation, and the assessments would have gone back to being non-threatened. Also note that longer segments would have resulted in much less variation. For example, if only a single twenty-year segment of the data in Fig. 4 had been available, there would be < 5% chance of calculating a reduction > 30% (this is because, of the 22 such segments, only one results in such a reduction).

The alternative suggestion by Fox et al. involves a "provisional threat classification," which is then adjusted using "expert judgement". This suggestion would lead to inconsistencies among assessments. The Red List process relies on expert judgment on several important steps, such as determining what the threats are, which, as discussed above, can offer clues about the expected patterns of decline. However, other aspects of the assessment, including the time window for calculating reduction, must be standardized for all species, in order to make the assessments comparable.

In many cases, selecting the correct pattern of decline is difficult, because threats are poorly known and variable in time. In such cases, statistical methods such as AIC and break-point analysis (segmented regression) can be used to determine which pattern is most supported statistically, and if there are changing threat levels in the past. In any case, reduction should be based on the last 10 years of the population trend fitted with these methods.

Even with sophisticated statistical methods, substantial uncertainties may remain. Red List Guidelines emphasize acknowledging all uncertainties, and encourage stating that more than one Red List category is plausible. Even if a species is listed as EN, for example, the assessment may state VU and CR as plausible categories. However, the uncertainty should not be used as a reason to avoid assessing a species, or to list it as Data Deficient (unless plausible categories include both CR and LC), or to relegate the listing decision to expert judgment.

The method described in the Red List guidelines of fitting longer than 10-year/3 generation time series data when available addresses the issue of inter-annual variability in population sizes. Calculating reduction based on the fitted population values reduces the dependence of the reduction on data from individual years. And, making this calculation for the last 10-years ensures standardization of the risk assessment process. Finally, the Red List guidelines allow and encourage incorporating and acknowledging uncertainties caused by not only natural variability and measurement errors but also by lack of information on threats. Assessors should not deviate from these guidelines. One possible source of confusion is the statement that fitting a time series longer than 10 years "may give a more representative estimate" of population reduction (IUCN Standards and Petitions Committee 2019; p. 32). This does not mean that using longer time series data, when available and reliable, is optional; rather, the statement implies that in some cases this process may not give a better estimate. This may be the case, for example, if the population is declining exponentially with little variation, in which case the length of time series makes little difference; or if part of the time series is not considered as reliable, in which case the assessors may choose to not use the whole time series. It may also be the case if the wrong model is used. For example, in Fig. 3, if a linear model is used instead of the logistic decline model, using the whole time series would mistakenly imply a reduction, while using only the data after the initial decline would give a more representative estimate of reduction.

Two related issues warrant brief discussion. Firstly, for short-generation species with currently stable or growing populations, declines that have taken place as recently as 11–20 years ago, even large declines as in the third example above, would not contribute to a threatened Red List status. Assessing such a species as Least Concern (as in Fig. 3) may seem inappropriate, because the large reduction is certainly a conservation concern. It is important to note that the category label Least Concern only refers to the risk of species extinction. It does not refer to other types of conservation concern, such as large historical declines resulting in severely depleted populations, and contributing to a shifting baseline. Such concerns are more appropriately incorporated into recovery assessments, by determining species recovery targets based on historical baselines, for instance with the new IUCN Green Status of Species (Akçakaya et al. 2018; Grace et al 2019), which complements the IUCN Red List. Conservation priorities should be based not only on the extinction risks of species (e.g., IUCN Red List) but also on how much they have been depleted relative to baseline conditions and on their potential for full recovery (e.g., IUCN Green Status of Species).

Secondly, for Red List assessment of most invertebrate species, the main difficulty is scarcity of data, especially widespread, long-term, standardized monitoring data (Didham et al. 2020; Hochkirch et al. 2020). Establishment of programs such as the UK Butterfly Monitoring Scheme (Botham et al. 2020) in countries rich in invertebrate diversity, engaging volunteer enthusiasm for charismatic taxa (Bried et al. 2020; van Strien et al. 2013), and employing entomological radar (e.g., biodarproject.org) and smart surveillance technologies (e.g., tumblingdice.co.uk), would go a long way in reducing uncertainties in the Red List status of these species.

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Declaration

Conflict of interest The authors declare that they have no conflict of interest.

References

Akçakaya HR, Bennett EL, Brooks TM, Grace MK, Heath A, Hedges S, Hilton-Taylor C, Hoffmann MK, Keith DA, Long B, Mallon DP, Meijaard E, Milner-Gulland EJ, Rodrigues ASL, Rodriguez JP, Stephenson PJ, Stuart SN, Young RP (2018) Quantifying species recovery and conservation success to develop an IUCN Green List of Species. Conserv Biol 32:1128–1138

Bried J, Ries L, Smith B, Patten M, Abbott J, Ball-Damerow J, Cannings R, Cordero-Rivera A, Córdoba-Aguilar A, De Marco JP, Dijkstra K-D, Dolný A, van Grunsven R, Halstead D, Harabiš F, Hassall C, Jeanmougin M, Jones C, Juen L, Kalkman V, Kietzka G, Searles Mazzacano C, Orr A, Perron MA, Rocha-Ortega M, Sahlén G, Samways M, Siepielski A, Simaika J, Suhling F, Underhill L, White E (2020) Towards global volunteer monitoring of odonate abundance. Bioscience 70:914–923

Didham RK, Basset Y, Collins CM, Leather SR, Littlewood NA, Menz MHM, Müller J, Packer L, Saunders ME, Schönrogge K, Stewart AJA, Yanoviak SP, Hassall C (2020) Interpreting insect declines: seven challenges and a way forward. Insect Conserv Divers 13:103–114

Botham M, Brereton T, Harris S, Harrower C, Middlebrook I, Randle Z, Roy DB (2020) United Kingdom Butterfly Monitoring Scheme: collated indices 2019. NERC Environ Inf Data Centre. https://doi.org/10.5285/657a64b2-8c34-43d2-a0f0-662ddf73c720

Fox R, Harrower CA, Bell JR, Shortall CR, Middlebrook I, Wilson RJ (2019) Insect population trends and the IUCN Red List process. J Insect Conserv 23:269–278

Grace M, Akçakaya HR, Bennett E, Hilton-Taylor C, Long B, Milner-Gulland EJ, Young R, Hoffmann M (2019) Using historical and palaeoecological data to inform ambitious species recovery targets. Phil Trans R Soc B 374:20190297

Hochkirch A, Samways MJ, Gerlach J, Böhm M, Williams P, Cardoso P, Cumberlidge N, Stephenson PJ, Seddon MB, Clausnitzer V, Borges PAV, Mueller GM, Pearce-Kelly P, Raimondo DC, Danielczak A, Dijkstra KDB (2020) A strategy for the next decade to address data deficiency in neglected biodiversity. Conserv Biol. https://doi.org/10.1111/cobi.13589

IUCN (2012) IUCN Red List Categories and Criteria: Version 3.1, 2nd edn. IUCN, International Union for Conservation of Nature, Gland, Switzerland and Cambridge, UK

IUCN Standards and Petitions Committee (2019) Guidelines for using the IUCN Red List categories and criteria. Version 14. Prepared by the IUCN SSC Standards and Petitions Committee. http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

van Strien AJ, Termaat T, Kalkman VJ, Prins M, De Knijf G, Gourmand A-L, Houard X, Nelson B, Plate C, Prentice S, Regan E, Smallshire D, Vanappelghem C, Vanreusel W (2013) Occupancy modelling as a new approach to assess supranational trends using opportunistic data: a pilot study for the damselfly *Calopteryx splendens*. Biodivers Conserv 22:673–686