

Comparative analyses of correlates of *Red data book* status: a case study using European hoverflies (Diptera: Syrphidae)

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Abstract

We present a comparative analysis of correlates of *Red data book* status that controls for phylogeny. As a model system we use 244 species of hoverfly (Diptera: Syrphidae) from the British fauna, with their *Red data book* statuses in Britain and three regions of Germany. The analysis is confined to four adult characters, with *Red data book* status as the dependent variable. Associated with an increase in risk of extinction were a decrease in flight period and an increase in wing length (in two regions). Variables representing the number of habitats occupied and whether species were single- or multi-brooded were not associated with an increase in risk of extinction. At this stage we restrict our analysis to the identification of patterns rather than speculation as to causal mechanisms, but the patterns themselves are of value to conservation biologists, provided the methods used to identify them control for the possible confounding effects of phylogeny.

INTRODUCTION

While far from perfect, *Red data book* status does give an indication of the degree of threat of extinction to a species (Mace & Lande, 1991; Mace & Stuart, 1994; Mace & Collar, 1995). As global extinction continues, understanding why species are at risk of extinction will help to inform decisions on the prioritization and implementation of conservation strategies (e.g. Smith *et al.*, 1993). The examination of correlates of *Red data book* status has been undertaken previously (e.g. for Finnish vascular plants, Lahti *et al.*, 1991; Scandinavian bryophytes, Lampolahti & Syrjanen, 1992; a variety of taxa of the Cape Floristic region, Rebelo, 1992; Spanish lycaenid butterflies, Munguira & Martin, 1993; endemic flora of the Cape Floristic Region, Willis, Cowling & Lombard, 1996; deforestation of island bird habitats, Brooks, Pimm & Collar, 1997). While some of these examples are descriptive, the identification of trends demands quantitative cross-species analysis. However, cross-species analyses should take account of phylogenetic relationships between species to draw statistically valid conclusions (Harvey & Pagel, 1991), which has not yet been done for correlates of *Red data book*

status. In such an analysis what is being tested are hypotheses about events in the evolutionary history of the phylogeny that predispose species to be currently placed in particular *Red data book* categories. For such an analysis to proceed, three sets of information need to be available: *Red data book* status (the dependent variable) for a reasonably large number of species; the phylogeny for that set of species; data for a number of independent variables. Biologists are now in a position to begin to have these factors in place for a variety of taxa, allowing the correct identification of correlates of extinction risk in those taxa, and eventually leading to general conclusions about extinction risk in animals. As a model system in which these kinds of information are available, we present an analysis of correlates of *Red data book* status in British hoverflies (Diptera: Syrphidae).

There are approximately 254 British species of hoverflies, and this fauna is reasonably well known due to a long history of collecting and recording (Stubbs & Falk, 1983). They are diverse, showing considerable variation in morphology, ecology, behaviour and life-history, indicating a large number of evolutionary events during the group's radiation. Much of the data on this variation are summarized in Stubbs & Falk (1983) and Stubbs (1996). Shirt (1987) and Falk (1991) provide *Red data book* status for the British hoverfly fauna. In

addition, and which makes our model system more generally applicable, there is overlap of this fauna onto continental Europe, and further *Red data book* statuses of these species are available for three regions of Germany (Baden-Württemberg: Doczkal *et al.*, 1993; Niedersachsen and Bremen: Stuke, Wolff & Malec, 1998; Saxony: Pellman *et al.*, 1996).

The present study examines correlations between *Red data book* status and variables representative of body size, flight period, number of habitats occupied and whether the species is multi-brooded or not in a sample of the British hoverfly fauna. It is hoped to identify which, if any, of these variables are associated with current level of threat to species in order to inform conservation management practices. While a negative relationship between body size and abundance is well documented in mammals (e.g. Peters & Wassenberg, 1983), the existence of such a relationship in insects is less clear (Gaston, 1988; Gaston & Lawton, 1988; Morse, Stork & Lawton, 1988; Owen & Gilbert, 1989). The 400-fold range of mass in the hoverflies (Owen & Gilbert, 1989) makes this group suitable for testing predictions about relationships between degree of threat and body size.

METHODS

Data on a sample of 244 British species of hoverflies were compiled from Stubbs & Falk (1983) and Stubbs (1996) (<http://149.170.199.144/biolsci/caicapp.htm>). Species included in the analyses were determined by their presence in the phylogeny and the availability of species information. Comparative Analysis by Independent Contrasts (CAIC, Purvis & Rambaut, 1995) was used to extract independent data points for analysis. A generic-level phylogeny was used (Rotheray & Gilbert, 1999), based on larval characters, and hence none of the characters used in the analyses were also used in the construction of the phylogeny. In the analyses that follow, *Red data book* (RDB) status is taken as the dependent variable. British RDB status has been coded as 1 = endangered, 2 = vulnerable, 3 = rare, 4 = notable and 5 = not in any of these categories. The RDB statuses from Doczkal *et al.* (1993) and Stuke *et al.* (1998) have been coded as 0 = extinct, 1 = close to extinction, 2 = very endangered, 3 = endangered, 4 = vulnerable, 5 = none of these. The RDB statuses from Pellman *et al.* (1996) have been coded as 0 = extinct, 1 = nearly extinct, 2 = very endangered, 3 = endangered, 4 = potentially endangered, 5 = reducing, 6 = none of these. Briefly, the criteria used for defining RDB categories for insects include the number of 10 km squares occupied (including whether the number occupied has shown a rapid and continuous decline over the last 20 years), the vulnerability of the habitats in which they occur, and whether population sizes are low. Number of habitat categories occupied (in Britain) is based on species descriptions in the sources cited above, with species allocated values of 1, 2, 3, or 4 or more habitats occupied, and we consider it to be generally a conserv-

ative estimate. The habitat categories encountered in the species descriptions were: mountains/upland; Caledonian forest; deciduous forest; conifer plantations; dry grassland; woodland and scrub edges; wet marsh or fen; bog or peat bog; heathland; coastal habitats; ditches, pond and lake margins; gardens and urban waste land; farmland; meadow; limestone pavement; moorland.

The sample size for individual analyses varies as the number of contrasts extracted by CAIC depends on which species have data available and the resolution of the phylogeny for those species. All continuous variables were log-transformed (RDB statuses log+1 transformed) as described by Cotgreave & Pagel (1997) to improve the normality of the residuals from subsequent regression analyses. All analyses were carried out using Minitab v.10.5 for the Macintosh (Minitab Inc., 1995) and all tests are two-tailed.

We used CAIC to generate contrasts for each of the three predictor variables ((log transformed) wing length, flight period and number of habitats occupied) on the dependent variable of (log +1 transformed) RDB status. This is done by entering all of the independent variables but specifying which is the one of interest, because the contrasts generated when more than one predictor is used vary slightly when each of the different predictors are specified. Thus for each set of RDB statuses, CAIC was run three times, specifying each of the independent variables in turn.

When testing a relationship between a dependent variable and a dichotomous predictor variable, in this case multi-brooded or not, CAIC produces a contrast for each evolutionary event at which the predictor variable changed state from, in this case, 0 to 1. This output therefore needs to be analysed using a one-sample *t*-test, or equivalent, to test whether the contrasts have a mean significantly different from zero.

RESULTS

Summary statistics for the variables considered, without any phylogenetic weighting and with sample sizes varying according to availability of data, are as follows. The hoverflies in this sample had (British data) a mean adult flight duration of 3.9 months, a mean wing length of 6.5 mm and fell into 1.1 of the habitat categories. Eighteen species were categorized as being multi-brooded and 185 species were categorized as single-brooded. The numbers of species in the various RDB categories are shown in Table 1.

We then conducted a series of multivariate regressions, through the origin, with contrasts in (log+1)RDB status as the dependent variable and contrasts in (log)wing length, (log)flight period and (log)number of habitats occupied as the predictor variables. Table 2 shows the effect of each of the predictors, controlling for the other two variables. In each case the overall ANOVA for the model is also given.

Contrasts in flight period were significantly correlated with contrasts in RDB status in all four regions. This indicates that a decrease in flight period is associated

Table 1. Numbers of species assigned to the four sets of *Red data book* categories

British RDB categories	Number of species	German RDB categories					
		Doczkal <i>et al.</i> (1993)	Number of species	Stuke <i>et al.</i> (1998)	Number of species	Pellman <i>et al.</i> (1996)	Number of species
1	8	0	2	0	7	0	3
2	10	1	2	1	3	1	9
3	10	2	13	2	12	2	17
4	60	3	33	3	13	3	25
5	155	4	16	4	20	4	25
		5	128	5	122	5	19
						6	98

with lineages currently being more at risk. Contrasts in wing length were significantly correlated with contrasts in RDB status in Britain and Baden-Württembergs, with an increase in wing length putting lineages more at risk. Number of habitats occupied was not associated with a change in extinction risk in any of the four regions. There was no significant tendency for RDB status to increase or decrease with change from single- to multi-brooded status in any of the four regions (Wilcoxon one-sample signed rank tests, all n.s.).

DISCUSSION

A considerable number of studies have addressed the relationship between abundance and body size in animals which, in general, find a negative relationship between body size and abundance assemblages (for a review, see Gaston & Kunin, 1997). We found a tendency for an increase in wing length in a lineage to put species more at risk of extinction, which would seem to be in general agreement with the thrust of these body size versus abundance relationships (recognizing that abundance and risk of extinction are rather different things). Body size, provided a number of individuals can be measured and notwithstanding individual variation, is a relatively quick piece of information that can be collected for a population or species, compared to, say, information on behaviour or life history. It is therefore useful for the pragmatic conservation biologist to have knowledge of this kind of relationship to hand. The causal relationship here is not clear. It may be that an increase in adult size during branching of a lineage is associated with increasing specialization, for example adults of the predacious Neuropteran *Chrysopa slossonae*, which had specialized aphid prey requirements, were larger than a non-specialized congener (Albuquerque, Tauber & Tauber, 1997). In hoverflies, some of this specialization may be at the larval stages;

species with saproxylic larvae, for example, include members with relatively large adults and may be particularly vulnerable as long-standing rot-holes become more scarce due to habitat destruction.

A strong relationship with risk of extinction was also found for flight period. There may be possible links between flight period and dispersal ability, with shorter flight periods indicating lower dispersal ability. In general terms, low dispersal ability has been found to indicate rarity (for a review, see Gaston & Kunin, 1997), although, again, the difference between rarity and risk of extinction makes extrapolation problematical. An increase in adult size and a decrease in flight period may both be components of a general life-history tactic allowing adults to cover greater distances while locating scarcer resources such as food, mating and oviposition sites. Denno (1994) found an increase in dispersal in planthopper species occupying more temporary habitats, and that migratory species were larger than non-migrants.

A change in the number of habitats occupied did not place species more or less at risk of extinction. This measure was intended to represent niche breadth, but a more appropriate measure might be the range of flower types visited by adults within a habitat category. A change in status between single- and multi-brooded within a lineage was not significantly associated with a change in RDB status.

Clearly, the mechanisms underlying the relationships described here need further elucidation. However, identification of patterns of vulnerability is a necessary first step in design and implementation of appropriate action. For example, within faunas and/or areas that are poorly known our results might suggest that action should be concentrated on the larger species within genera and those with shorter than average flight periods within genera. This paper shows how the range of information built up over many decades on the biology of a large group of insects can now begin to inform action for insect conservation.

Table 2. Results of multivariate regression analyses of contrasts of log(flight period), log(wing length) and log(number of habitats occupied) against the four regional (log+1 transformed) *Red data book* statuses

Region for <i>Red data book</i> status	Contrasts in log(flight period) as the main predictor variable					Contrasts in log(wing length) as the main predictor or variable					Contrasts in log(number of habitats occupied) as the main predictor variable				
Britain Shirt (1987); Falk (1991)	Predictor Flight period ANOVA	Coef. 0.275 <i>F</i> = 27.37; d.f. = 3,95; <i>P</i> <0.001	s.d. 0.0384	<i>t</i>-ratio 7.17	<i>P</i> <0.001	Predictor Wing length ANOVA	Coef. -0.3813 <i>F</i> = 25.67; d.f. = 3,95; <i>P</i> <0.001	s.d. 0.1062	<i>t</i>-ratio -3.59	<i>P</i> 0.001	Predictor <i>n</i> habitats ANOVA	Coef. 0.0059 <i>F</i> = 26.83; d.f. = 3,95; <i>P</i> <0.001	s.d. 0.039	<i>t</i>-ratio 0.15	<i>P</i> n.s.
Baden-Württembergs Doczkal <i>et al.</i> (1993)	Predictor Flight period ANOVA	Coef. 0.3431 <i>F</i> = 17.83; d.f. = 3,89; <i>P</i> <0.001	s.d. 0.0564	<i>t</i>-ratio 6.08	<i>P</i> <0.001	Predictor Wing length ANOVA	Coef. -0.402 <i>F</i> = 16.92; d.f. = 3,89; <i>P</i> <0.001	s.d. 0.146	<i>t</i>-ratio -2.75	<i>P</i> 0.007	Predictor <i>n</i> habitats ANOVA	Coef. -0.0099 <i>F</i> = 22.49; d.f. = 3,89; <i>P</i> <0.001	s.d. 0.0482	<i>t</i>-ratio -0.2	<i>P</i> n.s.
Niedersachsen und Bremen Stuke <i>et al.</i> (1998)	Predictor Flight period ANOVA	Coef. 0.8 <i>F</i> = 26.24; d.f. = 3,82; <i>P</i> <0.001	s.d. 0.0923	<i>t</i>-ratio 8.68	<i>P</i> <0.001	Predictor Wing length ANOVA	Coef. 0.3174 <i>F</i> = 42.74; d.f. = 3,82; <i>P</i> <0.001	s.d. 0.2058	<i>t</i>-ratio -1.54	<i>P</i> n.s.	Predictor <i>n</i> habitats ANOVA	Coef. -0.1104 <i>F</i> = 43.4; d.f. = 3,82; <i>P</i> <0.001	s.d. 0.063	<i>t</i>-ratio -1.75	<i>P</i> n.s.
Saxony Pellman <i>et al.</i> (1996)	Predictor Flight period ANOVA	Coef. 0.585 <i>F</i> = 22.3; d.f. = 3,88; <i>P</i> <0.001	s.d. 0.0726	<i>t</i>-ratio 8.06	<i>P</i> <0.001	Predictor Wing length ANOVA	Coef. -0.1517 <i>F</i> = 26.18; d.f. = 3,88; <i>p</i> <0.001	s.d. 0.1533	<i>t</i>-ratio -0.99	<i>P</i> n.s.	Predictor <i>n</i> habitats ANOVA	Coef. -0.0551 <i>F</i> = 35.55; d.f. = 3,88; <i>P</i> <0.001	s.d. 0.05112	<i>t</i>-ratio -1.08	<i>P</i> n.s.

In each cell the effect of the predictor variable is given (controlling for the other two predictors), together with the ANOVA for the overall regression model. Abbreviations used: Coef., coefficient; s.d., standard deviation; d.f., degrees of freedom.

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