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Reflections on the long-term assessment of ladybird (Coleoptera: Coccinellidae) populations in the Czech Republic and the United Kingdom

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Abstract. Large fluctuations in predatory ladybird populations between years makes it difficult to assess the conservation status of this important group of beetles. Monitoring of their long-term trends may be achieved using systematic structured surveys or by the collation of incidental records. Since the 1970s Alois Honěk and colleagues in the Czech Republic have used the former approach to generate some of the best long-term ladybird datasets globally. Declines in species, particularly *Coccinella septempunctata* Linnaeus, 1758, have been observed in these datasets, and explanations for the declines offered. Here we reflect on the work of Alois Honěk and colleagues and contrast their approach to monitoring ladybirds with that taken in the UK. UK ladybird trends have been derived from careful analyses of incidental records collected by citizen scientists, along with some systematic structured surveying. We compare the trends suggested by Czech and UK data. There are broad similarities in trends for several species, namely *Adalia bipunctata* (Linnaeus, 1758), *Coccinella undecimpunctata* Linnaeus, 1758 and *Propylea quattuordecimpunctata* (Linnaeus, 1758) (decreasing trends) and *Harmonia axyridis* (Pallas, 1773) and *Hippodamia* (*Adonia*) *variegata* (Goeze, 1777) (increasing trends). Conversely the trends for *Adalia decempunctata* (Linnaeus, 1758), *Coccinella quinquepunctata* Linnaeus, 1758, *C. septempunctata* and *Calvia quattuordecimguttata* (Linnaeus, 1758) are dissimilar in the two countries. We briefly explore whether similar drivers of change were at play in the Czech Republic and UK. In both countries, changes in agricultural practices (notably less small grain cereal-growing and reduced fertilizer use that lowers aphid numbers) may account for some of the ladybird population trends observed.

Key words. Citizen science, *Coccinella septempunctata*, Coccinellidae, Coleoptera, monitoring, population trends, systematic surveys, biological records.

INTRODUCTION

Populations of many insect species fluctuate substantially between years, perhaps especially so for predatory species such as many ladybirds (Coleoptera: Coccinellidae) that feed primarily on aphids (Honěk 1989, Majerus 1994). Such prey may be both ephemeral and highly variable in abundance (Dixon 2000). The effects of varying weather conditions are experienced by the predators directly; and indirectly through effects on prey populations. Thus, the task of making assessments of changes to ladybird populations is a difficult one, and ideally needs to be carried out over long time periods (at least ten years) and at large spatial scales (though see Pagel et al. 2014).

The monitoring of terrestrial insect populations to assess long-term trends tends to be conducted in one of two ways: systematic structured surveys (such as the UK Butterfly Monitoring Scheme – UKBMS), or; opportunistic approaches (such as the UK Ladybird Survey – UKLS) (Roy et al. 2011). Both methods can yield valuable information and for most taxonomic groups opportunistic approaches are the most practical and achievable for creating large-scale and long-term datasets.

However, systematic, structured surveys implemented over a large-scale (national) have enabled the clearest assessment of trends in biodiversity to be derived (Roy et al. 2007, van Swaay 2008). Such an approach relies on considerable commitment from volunteers because long-term funding is limited. There are, thus, few examples of such an approach (Thomas 2005).

The UKBMS, initiated in the UK in the 1970s and later extended to other parts of Europe, is one such exception (Pollard et al. 1995). Expert volunteers participating in the UKBMS record the abundance of butterfly species on transects carried out over a 26-week flight season. In the UK, 2105 transect routes have been walked since 1976, and whilst not all transects are recorded in every year, 991 sites were surveyed in 2012 (Botham et al. 2013). The UKBMS generates a vast dataset that enables detailed analyses of long-term trends in butterfly populations that has led to many high quality and high impact research outputs (e.g. Harding et al. 1995, Parmesan et al. 1999, Roy & Sparks 2000, Bennie et al. 2013). Additionally the data informs policy through a headline indicator for the UK Government (Defra 2014b). Butterflies, being generally popular, large and colourful insects that are readily identifiable in flight, clearly lend themselves to this kind of survey. Attracting volunteer recorders requires time and resources, but the collaboration between the Centre for Ecology & Hydrology alongside the non-governmental organisation Butterfly Conservation, has enabled effective coordination of the UKBMS.

Although ladybirds are amongst the most popular and prominent groups of insects, recruiting volunteer recorders to carry out regular surveys on a long-term basis (i.e. to the extent of the UKBMS) has largely proved unsuccessful, at least in the UK. This may be because of the smaller size and less obvious nature of ladybirds compared to butterflies, and/or the relative low number of volunteers and infrastructure to support ladybird recording (e.g. UKBMS is supported by Butterfly Conservation, a high profile membership conservation organisation). The volunteer-led Coccinellidae Recording Scheme (now re-named the UK Ladybird Survey – UKLS) was launched in 1971 as one of the national recording schemes overseen by the Biological Records Centre (www.brc.ac.uk). It has been highly successful in engaging a very large number of recorders to provide *incidental* records (opportunistic data) of ladybirds from across the UK and Ireland (Roy et al. 2011). Thus citizen science has been successfully employed for the collation of opportunistic data on the distribution of ladybird species across the UK. Using appropriate statistical methods, assessment of long-term trends in ladybird populations is possible using data collated by this approach (Roy et al. 2011).

In contrast to the UK, ladybird monitoring in the Czech Republic has tended to focus on a systematic approach over a limited number of sites. A relatively small team of dedicated researchers has generated some of the best long-term ladybird datasets globally. Indeed, we know of no longer-term ladybird datasets than those generated by Alois Honěk and colleagues from the 1970s to the present day (although see Alyokhin & Sewell 2004).

The 7-spot ladybird *Coccinella septempunctata* Linnaeus, 1758 has been of particular interest in the studies from the Czech Republic. *Coccinella septempunctata* is one of the most abundant predatory ladybirds in both the Czech Republic (Honěk 1989) and the UK (Roy et al. 2011) and indeed over much of the Palaearctic; its distribution stretches from Ireland in the west, across Europe and Asia, to Japan in the east (Kuznetsov 1997). It is also a highly successful introduced species in other parts of the world, notably North America, where it was used extensively from the 1950s as a biological control agent (Angalet & Jacques 1975, Gordon 1985, Turnock et al. 2003, Evans 2004). *Coccinella septempunctata* is a habitat generalist but has notable fluctuations in abundance over time, illustrating the need for long-term monitoring in order to make informed assessments of its conservation status.

In this paper, we re-visit the work of Honěk & Martinkova (2005) and the follow-up paper Honěk et al. (2014), and reflect on the contrasting approaches used in the Czech Republic and

UK in the long-term assessment of ladybird populations. We explore the possible causes for any long-term changes observed, comparing those assigned by Honěk & Martinkova (2005) and Honěk et al. (2014) to those we believe were at play in the UK. Whilst Honěk & Martinkova (2005) focused only on *C. septempunctata*, Honěk et al. (2014) take a broader approach, as we will here, in attempting comparisons of long-term trends in various ladybird species in the Czech Republic and UK.

LONG-TERM TRENDS

Whilst it is difficult to assess any similarities or differences in long-term ladybird trends from the Czech Republic and UK due to differing sampling strategies and time periods, some general comparisons may be made. There appear to be broad similarities in long-term trends for several species, namely *Adalia bipunctata* (Linnaeus, 1758), *Coccinella undecimpunctata* and *Propylea quattuordecimpunctata* (Linnaeus, 1758) (decreasing trends) and *Harmonia axyridis* (Pallas, 1773) and *Hippodamia* (*Adonia*) *variegata* (Goeze, 1777) (increasing trends) (Table 1). Conversely the trends for *Adalia decempunctata* (Linnaeus, 1758), *Coccinella quinquepunctata* Linnaeus, 1758, *C. septempunctata* and *Calvia quattuordecimguttata* (Linnaeus, 1758) are dissimilar in the two countries (e.g. *C. septempunctata* decreased in the Czech Republic but was stable in the UK). There are observations for four further species within the Czech Republic but these species do not occur in the UK.

For the species that appear to be thriving in both countries the mechanisms are perhaps the most straightforward to attribute. *Harmonia axyridis* is an invasive alien species that was a new arrival in both countries over the time periods considered, and has established and spread quickly (Brown et al. 2008, Špryňar 2008, Panigaj et al. 2014). In the case of *H. variegata*, we hypothesize that the species is benefitting from climate warming. It favours dry sandy soils and is very common in crop systems in southern Europe. In the UK *H. variegata* has become more common

Table 1. Comparison of long-term ladybird population trends in the Czech Republic and UK. Czech Rep. local trends from Honěk et al. (2014); UK national trends from Roy et al. (2011); UK local trends from standardised surveys nine times per year at each of four East Anglia sites (P. M. J. Brown unpublished data). * stable but decrease since arrival of *Harmonia axyridis*; ** stable but some indication of increase; N/A not applicable as species does not occur in the UK

species	Czech Republic local trend (1976–1983 vs. 2002–2010)	UK national trend (1990–2010)	UK local trend (2006–2013)	Czech Republic / UK trend agreement?
Adalia bipunctata	decrease	stable*	decrease	yes
Adalia decempunctata	increase	decrease	stable	no
Calvia decemguttata	increase	N/A	N/A	N/A
Calvia quattuordecimguttata	increase	decrease	stable	no
Ceratomegilla undecimnotata	increase	N/A	N/A	N/A
Coccinella quinquepunctata	decrease	stable	N/A	no
Coccinella septempunctata	decrease	stable	stable	no
Coccinella undecimpunctata	decrease	decrease	N/A	yes
Harmonia axyridis	increase	increase	increase	yes
Hippodamia septemmaculata	decrease	N/A	N/A	N/A
Hippodamia variegata	increase	stable**	N/A	yes
Oenopia conglobata	increase	N/A	N/A	N/A
Propylea quattuordecimpunctata	decrease	decrease	stable	yes

in northern England in recent decades (Roy et al. 2011), with signs that it has increased in parts of the country dominated by arable fields (notably East Anglia).

Of the species with declining trends, we suggest that in the case of *A. bipunctata*, *A. decempunctata* and possibly *P. quattuordecimpunctata*, the arrival of *H. axyridis* is at least a contributory factor in the UK. It is possible that such negative trends are observed in the UK but not the Czech Republic because the UK represents the edge of range for many European ladybirds and so the environment may be suboptimal. Hence the effects of alien species, such as the arrival of *H. axyridis*, and other interacting drivers of change may be more pronounced in the UK compared to regions at the core of a species range. In analyses derived from the UK datasets shown in table 1, Roy et al. (2012a) showed that an upward trend for *A. bipunctata* was reversed when *H. axyridis* arrived, and whilst *A. decempunctata* and *P. quattuordecimpunctata* were already declining in the UK before *H. axyridis* arrived, the declines steepened after its arrival. However, in some parts of the US the native *A. bipunctata* apparently declined decades ago, before the arrival of three non-native species. For example, Fothergill & Tindall (2010) indicate that *A. bipunctata* had already disappeared from south-eastern Missouri by 1970. Therefore, it is highly likely that a number of interacting factors are influencing the decline of this species. Frequently a coastal species in the UK, *C. undecimpunctata* has occasionally been highly abundant (notably in 1976, a hot and very good year for ladybirds in the UK) (Majerus 1994) but has been scarce in recent years for unknown reasons. *Coccinella undecimpunctata* is a smaller species than *C. septempunctata* and it may be that it is out-competed by *C. septempunctata* in most of the inland habitats in most years, with an exception in years when there are very high aphid numbers. The apparently restricted range of *C. undecimpunctata* to coastal habitats within the UK also suggest that this species is thermally limited.

There are few other long-term European ladybird studies to use as comparisons to the Czech and UK studies. However, a reflection on such studies from North America is possible. Most long-term datasets of *C. septempunctata*, *P. quattuordecimpunctata* and *H. axyridis* are largely focussed on their status as invasive alien species in North America. In Maine in potato crops, *C. septempunctata* increased dramatically over a 15 year period after its arrival, but its abundance was then apparently suppressed by the arrivals of *H. axyridis* and *P. quattuordecimpunctata* (Alyokhin & Sewell 2004). In alfalfa, in Manitoba, Turnock et al. (2003) show an inverse abundance relationship between the two dominant species, the alien *C. septempunctata* and the native *Hippodamia (Hippodamia) tredecimpunctata* (Linnaeus, 1758) (i.e. *C. septempunctata* abundance was higher when *H. tredecimpunctata* was lower, and vice versa). They hypothesize that *H. tredecimpunctata* was less affected by the arrival of *C. septempunctata* than were four other native species that declined following the arrival of the latter, and that this may have been due to competitive interactions partially linked to the sizes of the species (with the large species *Coccinella transversoguttata richardsonii* Brown being worse affected by the similarly large *C. septempunctata*). A similar study in alfalfa explored the arrival of four alien species (the three as in Alyokhin & Sewell 2004, plus *H. variegata*) over twelve and six year periods at two localities (Day & Tatman 2006). Similarly to the results of Alyokhin & Sewell (2004), the populations reported by Day & Tatman (2006) tended to fluctuate in a fairly regular pattern; additionally, a gradual increase in overall coccinellid numbers was caused by increasing numbers of *P. quattuordecimpunctata* and the native *Coleomegilla maculata* (DeGeer, 1776) (Day & Tatman 2006).

POPULATION STUDIES

The focus on opportunistic data within the UK enables distribution trends to be derived (Roy et al. 2011, 2012a) but systematic surveys would strengthen assessments of population trends

(Brown et al. 2011). Reassuringly the population trends derived from the small-scale systematic surveys in the East of England largely align with the large-scale distribution trends (Roy et al. 2012a). However, new analytical methods are being developed to integrate the information from local (small-scale) systematic (abundance) surveys with widespread (large-scale) opportunistic occurrence records and so enhance the value of these different datasets (Pagel et al. 2014). These authors have developed a hierarchical model that combines observations from multiple sources to derive spatio-temporal population trends. The hierarchical model structure, based on Bayesian statistics, relates to the links between population models (involving count data) and opportunistic observation models in which the data structure, quality and inherent uncertainty is explicitly included. Such an approach has been shown to improve estimates of population trends and provides an opportunity for collaborative analysis across datasets. Therefore, there is considerable potential to undertake analyses over much larger spatial scales than has historically been the case.

ARE CHANGING AGRICULTURAL PRACTICES RESPONSIBLE FOR SPECIES DECLINES?

Honěk & Martinkova (2005) and Honěk et al. (2014) present similar cases for changing agricultural practices being responsible for long-term declines in *C. septempunctata* abundance in the Czech Republic. There are two main facets of such agricultural change that are focussed on: firstly a decrease in acreage of small cereal crops favoured by *C. septempunctata* (important because of high acreage, high aphid abundance and formerly low insecticide use and late harvest date), with less suitable crops such as oilseed rape grown much more in later years (Honěk & Martinkova 2005, Honěk et al. 2014); secondly a reduction in fertilizer use, shown to lower aphid numbers (Duffield et al. 1997, Bianchi et al. 2007). Late harvest date for spring cereals appears to be a very important factor favouring coccinellid (*C. septempunctata* but also others such as *P. quattuordecimpunctata*) populations, since destructive mechanical cutting techniques earlier in the year in other crops, such as alfalfa and clover, could eliminate a large majority of the coccinellids in those fields (Honěk 1982). Some additional secondary facets are also outlined, including increased use of pesticides over time (Honěk & Martinkova 2005) (negatively affecting aphids and coccinellids) but decreased use of destructive harvest methods (positively affecting overwintering coccinellids) (Honěk & Martinkova 2005).

All of the above are reasonable conclusions to draw, but did similar changes to agriculture occur in Britain during this timescale? The answer to that question is broadly, yes. In the UK small grain cereals are heavily dominated by wheat and barley, which represent 97% of the total cereal acreage, and similar areas of each were grown in 1984 (Defra 2014a). In 2010 wheat acreage was the same as in 1984 (with minor fluctuations in between), but barley acreage reduced by 54% and oilseed rape increased by 2.4 times over the same period (Defra 2014a), cf. 4.1 times in the Czech Republic (Honěk & Martinkova 2005). Fertilizer use in the UK showed a substantial upward trend from 1973 (index of 127) to 1987 (index 187), followed by a substantial downward trend from 1987 to 2010 (index 100) (Defra 2014a). Pesticide application showed a general upward trend from 1973 to 2010 (Defra 2014a), though the available figures are crude measures that do not reveal anything about the selectivity and persistence of the treatments, which are presumed to have respectively increased, and decreased, thus likely limiting the effects on non-target species of increased pesticide use.

Whilst the long-term (1990–2010) trend for *C. septempunctata* in the UK is stable (Roy et al. 2011), this trend was derived from citizen-science collected data from the national recording scheme and does not necessarily reflect long-term data on *C. septempunctata* populations in crop systems (and no such data are available). Freier et al. (2007) report a ten year (1993–2002) dataset for *C. septempunctata* and *P. quattuordecimpunctata* in low- and high-input crop systems in Germany in which no clear trend is evident. For example, *C. septempunctata* adults were highly abundant in the first year of the study but fluctuate around a much lower level in subsequent years.

TRAITS AND TRENDS

There is considerable enthusiasm for recording coccinellids across Europe, particularly through citizen science initiatives, and potential to expand analysis and interpretation to enhance understanding of the ecology of this important group of insects. Furthermore, there is increasing interest in large scale ecological patterns and processes (Keith et al. 2012). Expanding collaboration across Europe (and beyond) to enhance the integration of coccinellid datasets could inform macro-ecological research, for example through traits-based models.

Combining traits-based models (Comont et al. 2012) with hierarchical models can contribute to elucidating the mechanisms underpinning trends by deriving hypotheses to test empirically. Indeed, traits of vertebrates and plants have been used to explore patterns of distribution (Pocock et al. 2006, Blackburn et al. 2009), but relationships between invertebrate traits and distribution patterns has received less attention (Comont et al. 2012, Fox et al. 2014). Life-history and resource-use traits are relatively well understood for many species of ladybird because of the extensive research, particularly in relation to biological control (Dixon 2000, Hodek et al. 2012). Therefore, ladybirds provide an excellent study system for traits-based research.

In a recent study it was revealed that diet breadth was correlated with the range size of ladybirds in the UK (Comont et al. 2012). In a subsequent study traits were combined with spatio-temporal trends in the distribution patterns of ladybirds (Comont et al. 2014). The complex results revealed that the distribution dynamics of ladybirds are influenced by a number of factors, including intrinsic traits of ladybirds, but also extrinsic factors such as climate and the presence of the alien species *H. axyridis*. Such modelling approaches using large-scale and long-term datasets linked to species traits and environmental factors provide a basis for formulating hypotheses in relation to the mechanisms driving change. However, it will be interesting to explore the relevance of these traits between countries. Indeed, the variation in traits between regions would provide fascinating insights into the intraspecific phenotypic variability of ladybirds and potential links with population and distribution trends.

CONCLUSIONS

The inspiring datasets from the work of Alois Honěk and colleagues since the 1970s has provided a unique insight into the ecology of coccinellids in Europe. It is exciting to consider the potential future collaborations extending to a network across Europe. The methods employed in the Czech Republic and the UK (alongside other European countries) could be linked through emerging analytical techniques providing the capacity to address ecological questions on a continental-scale.

Historically, modelling approaches have focused on single trophic-levels or taxonomic groups, but the potential to combine datasets across taxa and trophic levels using hierarchical approaches is exciting (Roy et al. 2014). Possible examples include integrating data on aphid distributions from suction traps (such as the Rothamsted Insect Survey) (Harrington & Woiwood 2007) with coccinellid datasets (systematic surveys and opportunistic data). The Rothamsted Insect Survey has collected aphid data since 1964 in the UK and was later expanded to other parts of Europe as part of the Examine network; the Czech Republic joined in 1994 and has a network of five traps (Rothamsted Research 2014). The dataset of Honěk et al. (2014) includes detailed habitat information, including plant species, alongside the observations of coccinellids. Distribution datasets such as that collated through the UK Ladybird Survey are increasingly including detailed habitat information for each occurrence record. Such information-rich datasets will provide opportunities for detailed analyses and it is appealing to consider the potential for exploring networks of species (Roy & Lawson Handley 2012) and their habitats in spatio-temporal contexts.

Coccinellids have captured the imagination of many people, not only scientists, throughout history (Majerus, 1994). Citizen science (Roy et al. 2012b) is a relatively new term but the involvement of volunteers in recording ladybirds extends over centuries. Citizen science provides opportunities to engage people beyond fascination and interest in a subject, to actively contributing to "real" science. As technology advances there are increasingly diverse ways in which citizen scientists can interact collaboratively with professional scientists to enhance ecological understanding. We look forward to addressing increasingly complex questions through both mass participation and co-created citizen science projects. Additionally, we hope that detailed long-term field studies such as those conducted by Alois Honěk and colleagues will continue long into the future.

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