Insect Conservation and Diversity

*Insect Conservation and Diversity* (2015) doi: 10.1111/icad.12124

MINOR REVIEW

# Testing the applicability of regional IUCN Red List criteria on ladybirds (Coleoptera, Coccinellidae) in Flanders (north Belgium): opportunities for conservation

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**Abstract.** 1. Red Lists assess the extinction risk of species and are an important tool to prioritise species conservation and management measures. Worldwide, quantitative IUCN criteria are used to estimate the threat status of species at the regional level.

2. In Flanders (north Belgium), about 70 000 distribution records of ladybirds were collected in 36% of all the grid cells ($1 \times 1$ km$^2$) since 1990 during a large-scale citizen-science project.

3. Applying the IUCN criteria to the 36 resident 'conspicuous' ladybirds in Flanders resulted in two *Regionally Extinct* species, three *Endangered* species and six *Vulnerable* species. A further seven species were considered *Near Threatened* and the remaining 15 species (39%) were assessed as *Least Concern*. Three species were classified as *Data deficient*. Using the Red List status, we delineated ladybird hotspots that were mainly located in grid cells with large areas of Natura2000 sites.

4. For calculating a distribution trend, we advocate the use of a high grid cell resolution (e.g. $1 \times 1$ km$^2$ or $5 \times 5$ km$^2$).

5. The ladybird data set from Flanders provides evidence that IUCN Red List criteria can be applied to this charismatic, but relatively under-surveyed insect group. For estimating the geographic range, the use of extent of occurrence instead of area of occupancy is advisable when the survey coverage is relatively low. We discuss the opportunities of the availability of a ladybird Red List for regional conservation measures.

**Key words.** Citizen science, conservation, distribution, hotspots, threatened species.

## Introduction

Red lists play an important role in generating public and policy support for species conservation (Rodrigues *et al.*, 2006). Listing species according to their relative risk of extinction and comparing regularly updated Red Lists, is a powerful tool in assessing the efficacy of species conservation policies (Mace *et al.*, 2008). With effective conservation management and adequate policy measures (e.g. species protection), species can either improve their Red List status, or can, despite conservation action or because of lack of it, remain or become even more threatened (e.g. the Red List Index – Butchart *et al.*, 2005). Red Lists are also an important tool in prioritising expenditure of limited available funds and personnel for species conservation purposes. Moreover, from an ethical point

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of view, the Red List process takes an *intrinsic value* approach, assuming all species are equal (Samways, 2005). For lesser known groups of insects or invertebrates, the process of Red Listing, therefore, contributes to awareness raising for the conservation of species that are often less popular than the more conspicuous taxonomic groups. Birds, mammals, plants, butterflies and dragonflies, for example, can more easily induce a willingness-to-pay for nature conservation with the public (Cardoso *et al*., 2011b).

In the case of insects and invertebrates in general, however, it has been noted that Red Lists principally reflect the state of knowledge rather than the actual status of a species' extinction risk (Cardoso *et al*., 2012). Measurement error is by far the greatest factor of uncertainty in insect Red List assessments (Akçakaya *et al*., 2000). Based on a comparison between consecutive assessments of British butterflies, the current IUCN criteria are considered a more valid assessment of extinction risk than earlier versions (Warren *et al*., 1997; Fox *et al*., 2011). They are, however, mostly applicable to species for which comprehensive quantitative data are available. In general, the paucity of detailed data on range sizes or trends for most invertebrates, renders the Red List compilation, in principle, more difficult (Cardoso *et al*., 2011a; Fox *et al*., 2011).

The number of coccinellid species worldwide is estimated at about 5000 species, representing 2% of the world's Coleoptera biodiversity (Bouchard *et al*., 2009; Roy & Majerus, 2010). About 110 of these species, including species acclimatised since the 1900s, occur in Europe depending on the coccinellid taxonomy followed (Iperti, 1999). In Belgium, about 70 native species have been reported of which 80% are principally carnivorous (Majerus, 1994a; Klausnitzer & Klausnitzer, 1997). Both adults and larvae of carnivorous ladybird species feed on aphids, coccids, whitefly or mites, which can inflict damage to crops and garden plants. The majority of ladybirds are therefore of great importance as natural predators of agricultural or garden pests (Dixon, 2000). Consequently, they have received considerable research attention as potential biocontrol agents against homopterous insects and mites (Roy & Migeon, 2010). Furthermore, they are generally considered iconic flagship species of well-functioning ecosystems providing regulating services to mankind (Pell *et al*., 2008). The first case of classical biological control with the Australian vedalia ladybird *Rodolia cardinalis* (Mulsant), which was introduced in 1888 in California, saved the citrus industry from cottony cushion scale (*Icerya purchase* Maskell) outbreaks. This certainly fuelled the beneficial way ladybirds have been perceived by the public (Dixon, 2000). Besides their value in pest regulation, ladybirds can also be used as indicator species for changing ecological conditions (e.g. Nummelin, 1998). Coccinellids can be stenotopic or eurytopic, with many species of ladybirds exhibiting a preference for specific vegetation types, microclimatological conditions or habitat strata (Majerus, 1994a; Adriaens *et al*., 2008). However, to use species as bio-indicators of environmental change, a predictive understanding of the responses of these target taxa to environmental stress or disturbance at various spatial and temporal scales is necessary (Andersen, 1999). Although this knowledge is often lacking for invertebrate groups, ladybirds are promising candidates as biodiversity indicators to identify the diversity of taxa and, more generally, to monitor changes in biodiversity in a specific habitat (McGeoch, 1998). Similarly, it has been shown that conspicuous and easily recognisable insect taxa in multispecies umbrella groups can be effectively used as a surrogate for species richness of lesser known groups and for assessing habitat quantity and quality (Hughes, 2000; Kerr *et al*., 2000; Maes & Van Dyck, 2005). This way, an assessment of the status of ladybirds could be a proxy for less conspicuous insects forming a part of the same aphid feeding guild such as lacewings (Neuroptera, Chrysopidae) and larvae of midges (Diptera, Cecidomyiidae) or hoverflies (Diptera, Syrphidae).

Despite the general recognition of the cultural heritage they represent and the ecosystem services they provide, the inclusion of ladybirds in conservation and management planning is currently limited (Cardoso *et al*., 2012; Collen & Böhm, 2012). Also, unlike the more popular insects such as butterflies (van Swaay *et al*., 2011), dragonflies (Kalkman *et al*., 2010) and saproxylic beetles (Nieto & Alexander, 2010), there is a general paucity of regional Red Lists of insects in general and ladybirds in particular making use of the IUCN criteria (IUCN, 2003), albeit with some exceptions (e.g. Norway – Ødegaard *et al*., 2010; Germany – Geiser, 1998). Examples of species protection policy, species action plans or environmental impact assessments for ladybirds are scarce. Besides lack of knowledge on autecology of many insect species, among others, an important reason for this could be the lack of a European or a regional Red List.

At present, all indigenous Coccinellidae in Flanders (north Belgium) have received basic juridical protection through the Flemish Government Decision of 15/05/2009 on species protection and species management. A threat status according to a Red List assessment, however, is a prerequisite for setting up species regional action plans (Species Decree Flemish Government 15/05/2009). The current lack of conservation priorities and actions for this important functional group and the availability of extensive new data sets, warrant a Red List assessment for ladybirds in Flanders. The aim of this paper is, therefore, to undertake such an assessment with the IUCN criteria (IUCN, 2003) and the guidelines for their application at regional levels (Gärdenfors, 2001; Maes *et al*., 2011). Furthermore, we identify conservation priority locations for ladybirds (*hotspots* – Prendergast *et al*., 1993), address the underlying causes of their threat status and discuss the policy implications of this listing exercise.

## Material and methods

### *Study area*

Belgium is a federal country with three administrative regions: Flanders, Wallonia and the Brussels Capital Region each having their own regional government (Fig. 1). Species protection policy is a competence of the regional governments and it is, therefore, appropriate to compile Red Lists per administrative region rather than for Belgium as a whole. Here, we focus on the Red List assessment in Flanders (±13 500 $km^2$), the northern part of Belgium. 8.3% of its area is protected under different nature conservation legislations (private nature reserves, Habitat Directive areas etc. – Van Steertegem, 2009). The region is characterised by a very high population density (466 $km^{-2}$ – Vanweddingen, 2012), 26% of built-up land, an extreme degree of urban sprawl and a landscape consisting of a highly fragmented and complex mosaic of different forms of land use (Poelmans & Van Rompaey, 2009). This imposes a high pressure on semi-natural biotopes (Dumortier *et al.*, 2007) with habitat fragmentation and habitat quality loss as the major drivers of biodiversity loss in Flanders (Maes & Van Dyck, 2001).

### *Species data*

In Belgium, a large-scale ladybird mapping project running since 1990 and involving numerous skilled volunteer recorders collecting opportunistic data (i.e. verified citizen-science sensu Gardiner *et al.*, 2012 with most observations underpinned with pictures), generated detailed knowledge of ladybird distributions at a high resolution (i.e. 1 × 1 $km^2$ grid cells) (survey methods described in Adriaens *et al.*, 2008). Since 2008, the use of online recording and mobile phone applications also greatly increased both the number of ladybird observations and the spatial resolution of ladybird records. In total, 70 724 records of ladybirds were collected in Flanders since 1830. If we only consider condensed records (species, year, 1 × 1 $km^2$ grid cell), the number of records amounts to 35 085. The number of records and the number of grid cells surveyed since 1990 are given in Table 2.

Flanders has 70 indigenous ladybird species (Adriaens & Maes, 2004; Bogaert, 2008). The subfamilies of *Scymninae* (30 species – Lock *et al.*, 2007; Bogaert *et al.*, 2012) and *Coccidulinae* (four species) are not easy to identify and are strongly under-represented in this citizen-science survey (Adriaens & Maes, 2004). They were, therefore, excluded from this Red List assessment. The 36 species of the three other subfamilies (so called *conspicuous* ladybirds) were assessed against the IUCN criteria: *Chilocorinae* (five species), *Coccinellinae* (28 species) and *Epilachninae* (three species). Two ladybird species were not evaluated because of their doubtful origin or classification: *Hippodamia undecimnotata* (Schneider 1792) (probably vagrant) and *Adalia conglomerata* (L. 1758) [possibly a misidentified *Tytthaspis sedecimpunctata* (L. 1761)]. In line with the IUCN criteria, four introduced species were also not evaluated: the introduced invasive alien harlequin ladybird *Harmonia axyridis* Pallas 1773 (Adriaens *et al.*, 2003), *Cryptolaemus montrouzieri* Mulsant 1853 (unpubl. data), *Rhyzobius forestieri* (Mulsant 1853) (Bogaert, 2008) and *R. lophanthae* (Blaisdell 1892) (Van den Heuvel, 1988).

### *The regional IUCN criteria*

The IUCN uses 11 categories for listing species in regional Red Lists (Mace *et al.*, 2008). Three categories refer

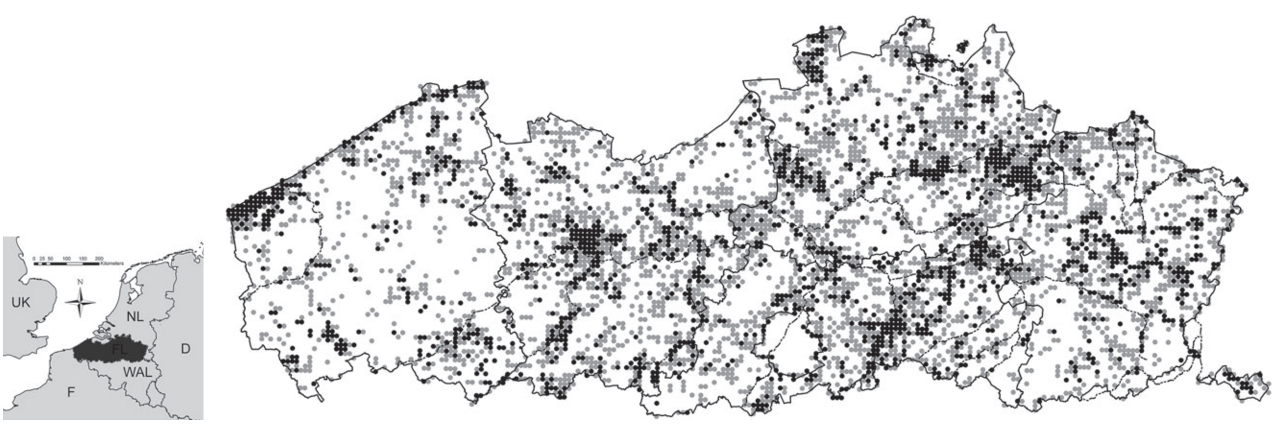


**Fig. 1.** UTM 1 × 1 $km^2$ grid cells in Flanders (north Belgium) that were surveyed since 1990 (in grey). The grid cells surveyed in both periods (1990–2005 and 2006–2013) were used to calculate changes in distribution area and are shown in black (inset: FL = Flanders, WAL = Wallonia, D = Germany, NL = the Netherlands, F = France, UK = United Kingdom; Brussels Capital Region is located at the blank central region on the large map).

to extinct species: *Extinct* (EX – globally extinct species), *Extinct in the Wild* (EXW – the species only persists in captivity) and *Regionally Extinct* (RE – extinct species in the focal region). Five categories are used to classify species in different extinction risk categories: *Critically Endangered* (CR), *Endangered* (EN), *Vulnerable* (VU), *Near Threatened* (NT) and *Least Concern* (LC). The three remaining categories are *Data Deficient* (DD – insufficient data available, e.g. cryptic or inconspicuous species), *Not Applicable* (species for which the Red List criteria do not apply, e.g. introduced species) and *Not Evaluated* (species not yet evaluated against the Red List criteria, e.g. migrant species, ill-surveyed species). Five criteria are used to classify species in the different Red List categories: (i) Population reduction during the last 10 years, (ii) Geographic range, (iii) Small population size and decline, (iv) Very small or restricted population and (v) Quantitative analysis of extinction risk (Mace *et al*., 2008).

For the Red List classification of ladybirds in Flanders, we only used IUCN criteria A and B (Table 1). Criteria C and D could not be used because these criteria rely on knowledge of absolute population numbers (i.e. number of individuals). These are not readily available for ladybirds and are hard to get for invertebrates in general (Régnier *et al*., 2009; Cardoso *et al*., 2012). Criterion E was also not used because until now no attempt to quantitatively analyse the future extinction risk (e.g. through population viability analysis) has been performed on ladybird species in Flanders.

*Criterion A: population reduction*. Since no abundance data are available for ladybirds in Flanders, we calculated the changes in distribution area between the periods 1990–2005 and 2006–2013 by counting the number of $1 \times 1$ km$^2$ grid cells in which a species occurred in each period (2079 and 4219 respectively) as a proxy for population change. We used time periods of different length to obtain an equal number of data in both periods with the rationale that a longer, but less intensively surveyed reference period would compensate for a shorter but more intensively surveyed recent period (Table 2). Furthermore, to correct for spatial differences in both sampling periods, we limited the analysis to the grid cells that were surveyed in both periods ($N = 1475$ – Fig. 1). For each species, we subsequently calculated a relative distribution area per period by dividing the number of grid cells in which the species was observed by the total number of commonly investigated grid cells. To calculate a change in distribution area between the period 2006–2013 and the period 1990–2005, we used the following formula:

$$\text{Trend} = 100 \times \frac{(\text{relative distribution } 2006-2013) - (\text{relative distribution } 1990-2005)}{(\text{relative distribution } 1990-2005)}$$

Since the introduction of the invasive alien species *H. axyridis*, several native ladybird species have declined in Belgium (Roy *et al*., 2012). For those species with a significant decline in Belgium, we used this information under criteria A2(e), i.e. a negative effect of introduced taxa and B1(b(v)), i.e. a continuing decline in the number of individuals.

*Criterion B: geographic range*. As geographic range, we calculated the extent of occurrence (EOO) by summing the area of the ecological districts in Flanders ($n = 36$ – Fig. 2) in which a species was observed in at least three $1 \times 1$ km$^2$ grid cells in the period 2006–2013. These ecological districts are homogeneous with respect to abiotic characteristics which are slowly changing in time (e.g. climatology, geology, relief, geomorphology) and have similar landscape, soil and biotope types (Couvreur *et al*.,

**Table 1.** IUCN criteria and thresholds (cf. Mace *et al*., 2008) used to classify ladybirds in the different IUCN Red List categories in Flanders.

| Red List category | | *Critically Endangered* | *Endangered* | *Vulnerable* | *Near Threatened* |
|---|---|---|---|---|---|
| Criterion A2c: reduction in population size based on a decline in area of occupancy (AOO) | | | | | |
| Criterion A2e: reduction in population size based on the effect of introduced taxa, i.e. the invasive alien *Harmonia axyridis* (Roy *et al*., 2012) | | | | | |
| | | ≥80% | 50–80% | 30–50% | 20–30% |
| Criterion B1: geographic range size (extent of occurrence as the sum of the area of the ecological districts in which a species was observed) | | | | | |
| Extent of occurrence (EOO) | | <100 km$^2$ | <5000 km$^2$ | <20 000 km$^2$ | |
| And two of the subcriteria (a) and (b) | | | | | |
| a | (i) severely fragmented | | | | |
| | (ii) number of locations | 1 | 2–5 | 6–10 | 11–20 |
| b | (ii) decline in AOO | | | | |
| | (iii) decline in area of occupancy, extent of occurrence and/or quality of the habitat | | | | |
| | (iv) decline in the number of mature individuals due to the arrival of *Harmonia axyridis* (Roy *et al*., 2012) | | | | |

**Table 2.** Number of records (species, grid cell, year) and the number of surveyed 1 × 1 km$^2$ and 5 × 5 km$^2$ grid cells in the periods 1990–2005 and 2006–2013. A subset of these records was used to calculate distribution changes of ladybirds in Flanders. The percentage between brackets refers to the percentage of investigated grid cells in both periods ($N$ = 13 609, 1 × 1 km$^2$ grid cells; $N$ = 647, 5 × 5 km$^2$ grid cells).

| Period | 1990–2005 | 2006–2013 | Total |
|---|---|---|---|
| Number of records | 10 487 | 18 636 | 29 123 |
| Number of 1 × 1 km$^2$ surveyed grid cells | 2079 (15%) | 4219 (31%) | 4977 (36%) |
| Number of 5 × 5 km$^2$ surveyed grid cells | 524 (81%) | 610 (95%) | 619 (96%) |

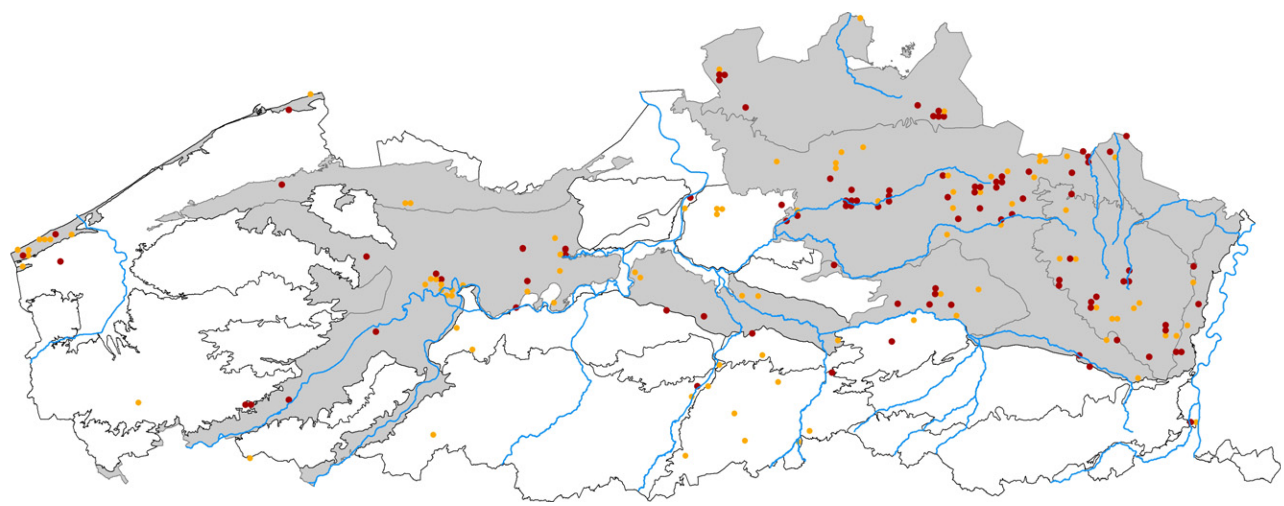

**Fig. 2.** Ladybird hotspots in Flanders (N Belgium) based on the Red List status of the species composition per 1 × 1 km$^2$ grid cell: *Critically Endangered* species are scored 80, *Endangered* species 50, *Vulnerable* species 30, *Near Threatened* species 20, *Data deficient* species 10 and *Least Concern* species are scored 1). Grid cells with a very high conservation priority (extinction risk value ≥85, $n$ = 95) are shown in dark red, grid cells with a high conservation priority (extinction risk value between 65 and 84, $n$ = 93) are shown in orange. Boundaries delineate ecological districts (see Fig. S1). The districts with the highest number of (very) high conservation priority grid cells are shaded in grey.

2004; Fig. S1). The minimum number of three grid cells per ecological district was applied to exclude single observations of vagrant or erratic individuals. Additionally, we used the following subcriteria:

1. a(i), i.e. populations are highly fragmented (assessed visually on distribution maps) and/or a(ii), i.e. the number of known populations is low (< 10 locations);
2. b(ii), i.e. a decline in AOO, this largely coincides with criterion A2(c);
3. b(iii), i.e. a decline in biotope quality for species (based on Adriaens *et al.*, 2008) that are typical for nutrient-poor grasslands, heathlands, marshes. These biotope types show a declining habitat quality due to a high pressure of atmospheric nitrogen deposition and desiccation (Schneiders *et al.*, 2007) and are therefore considered as the most threatened biotopes in Flanders (Van Landuyt, 2002);
4. b(v), i.e. a declining trend in the number of individuals due to the arrival of the invasive alien species *H. axyridis* (Roy *et al.*, 2012).

Each species was assigned to the highest Red List category obtained by either criterion A or B (Mace *et al.*, 2008).

*Downgrading of Red List categories.* In a first step, regional Red List classifications were carried out using the IUCN criteria as described above. Nevertheless, according to the IUCN criteria for regional levels (IUCN, 2003), the resulting IUCN Red List category from this assessment should be downgraded by one category if populations in neighbouring regions can exert a rescue effect on the populations in Flanders. Since Flanders is a relatively small region (±13 500 km$^2$) surrounded by regions/countries with a similar ladybird fauna, this rescue effect is possible for a number of species. To take the possible rescue effect into account, we used the rarity and the trend in distribution of the species in (either) the Netherlands (www.stippen.nl) and/or Wallonia (S Belgium – San Martin y Gomez *et al.*, 2006). When a species was assessed as common in one of the neighbouring regions, we downgraded it with one Red List category.

### Ladybird hotspots

To determine priority areas for ladybird conservation, hereafter called hotspots, in Flanders, we assigned numeric values to each Red List category: 80 for CR species, 50 for EN species, 30 for VU species, 20 for NT species and 1 for LC species. These values correspond to the threshold values of criterion A2 (cf. Maes *et al.*, 2012). Using the species composition of each 1 × 1 $km^2$ grid cell since 2006, we subsequently summed these values to obtain an *extinction risk value* per grid cell. Grid cells with an extinction risk value ≥85 were considered as a very high conservation priority, grid cells with an extinction risk value between 65 and 84 were considered as a high conservation priority for ladybirds.

## Results

Applying the new IUCN criteria and their subcriteria to the indigenous ladybird species in Flanders resulted in two RE species, three EN species and six VU species (Table 3). A further seven species were considered NT and the remaining 15 species (39%) were assessed as LC. Three species were classified as DD (Table 3). In total, 31% of the ladybird species in Flanders were considered RE (6%) or threatened (CR, EN or VU – 25%).

Most of the 1 × 1 $km^2$ grid cells with a (very) high conservation priority in Flanders (59%) are located in the northeast of the region. This sandy region has a warmer microclimate than the rest of Flanders and holds most of the large heathlands, marshes and nutrient-poor grasslands with its typical and threatened ladybird fauna. Additional ladybird hotspots are located in the Pleistocene river valleys (18%) and along the western part of the coast (5% – Fig. 2). Grid cells with a (very) high conservation value for ladybirds have significantly larger areas of Natura2000 sites than medium and/or low conservation value sites (Fig. 3).

## Discussion

The availability of high-resolution data on the distribution and habitat preferences of ladybirds in Flanders (north Belgium) permitted application of the IUCN criteria to this relatively less intensively surveyed invertebrate group. The IUCN Red List for ladybirds in Flanders revealed that 31% of the species were RE, CR, EN or VU. This Red List will permit prioritisation of conservation efforts into ecological regions where a large number of threatened ladybirds co-occur and will draw attention to appropriate management and policy measures.

### *Data quality and IUCN criteria*

Despite the familiarity and popularity of ladybirds with the wider public, only 4219 grid cells of 1 × 1 $km^2$ (31% of all grid cells in Flanders) had at least one ladybird record in the period 2006–2013. The number of recently surveyed grid cells is considerably lower for ladybirds than for other insect groups such as butterflies (86%) and dragonflies (40%). About one-third of the surveyed grid cells for ladybirds ($n$ = 1475, 11% of all grid cells in Flanders) were mapped in the two periods we used here to calculate changes in distribution (1990–2005 vs. 2006–2013). The use of commonly surveyed grid cells to calculate distribution trends is advisable to avoid differences in geographic coverage between the two compared periods. For this analysis, we used grid cells with at least one observation in both periods; more stringent criteria (e.g. two or more observed species in both periods) resulted in similar trend calculations, but decreased considerably the number of grid cells that could be used for the trend calculations. The use of high-resolution grid cells (i.e. 1 × 1 $km^2$) to calculate distribution trends is preferred to avoid the underestimation of changes in distribution (Thomas & Abery, 1995; Maes *et al.*, 2012). In our case, however, if 5 × 5 $km^2$ grid cells had been used, trends would have been similar (Spearman correlation between the trend calculated with 1 × 1 $km^2$ grid cells and 5 × 5 $km^2$ grid cells, $r$ = 0.864). The high correlation in distribution trends between the high resolution (1 × 1 $km^2$ grid cells) and the coarser resolution grid cells (5 × 5 $km^2$) is due to fact that the number of surveyed 1 × 1 $km^2$ grid cells within a 5 × 5 $km^2$ grid cell is low, resulting in similar numbers of occupied grid cells: on average, per 5 × 5 $km^2$ grid cell 5.7 grid cells of 1 × 1 $km^2$ were surveyed since 2006 resulting in a small *range fill*. For comparison, the average number of surveyed 1 × 1 $km^2$ grid cells per 5 × 5 $km^2$ grid cell in butterflies is 17.2 resulting in a much higher *range fill* causing larger differences in trend calculations when using either high or coarse resolution grid cells (Maes *et al.*, 2012). A species was considered present in a square as soon as one individual was observed. Therefore, a decline in the coarse resolution grid cell (5 × 5 $km^2$) can only be observed when a species is lost from all of the 1 × 1 $km^2$ grid cells within the 5 × 5 $km^2$ grid cell. The use of high-resolution grid cells (1 × 1 $km^2$) is, therefore, advocated to calculate trends for species with a relatively small range (e.g. ladybirds, butterflies, grasshoppers), while grid cells with a coarser resolution (5 × 5 $km^2$ or even 10 × 10 $km^2$) can be used for species with larger ranges (e.g. mammals, birds – Gaston & Fuller, 2009). For many taxonomic groups such high-resolution data are unavailable, however.

Many invertebrates have strongly fluctuating short-term population trends that might not accurately reflect long-term trends. Therefore, short-term census data may be affected by fluctuations in densities (Thomas *et al.*, 2011). Due to annual and even seasonal changes in aphid outbreaks and plant species infested (Honek & Martinková, 2005), this is especially true for ladybirds and, thus, on the behaviour and distribution of coccinellids (Majerus, 1994a). Long-term studies on coccinellid abundance, however, are mainly focussed on agricultural ecosytems and, more rarely, on (semi-)natural ecosystems (Honek *et al.*, 2014). In the absence of long-term quantitative data on adult numbers of ladybirds in Flanders, we used the

**Table 3.** The Red List of Ladybirds in Flanders (north Belgium) with the different IUCN criteria applied to classify the species. IUCN criteria used to classify ladybirds in the Red List of Flanders (north Belgium). Criterion A2 and B1 represent the IUCN criteria used to compile the Flemish Red List (see Table 1); if a species meets one of the criteria, the resulting Red List category and the criteria are given between square brackets; '–' means none of the species met the criteria; the highest threat category per species is given in bold. If the historical decline is lower than 50% it is indicated with '–'. Wal, NL and UK are the status and trend in Wallonia (south Belgium), the Netherlands and the UK respectively, r means rare, c means common; (+), (−) or (o) refer to an increasing, decreasing or stable trend respectively according to the references mentioned in the text, '–' means that the species is absent from the region or the country. The comments indicate whether a species was downgraded to obtain the final Red List category for Flanders. Species names are according to Fauna Europaea (http://www.faunaeur.org/). Rescue effect = Yes when a species is at least common in Wallonia or in the Netherlands.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Regionally Extinct (RE) – 2** (between brackets the last year of observation in Flanders) | | | | | | | |
| *Hippodamia septemmaculata* (1929) | | | | | | | |
| *Sospita vigintiguttata* (1859) | | | | | | | |
| **Critically Endangered (CR) – 0** | **Criterion A2c** | **Criterion B1 (EOO)** | **Wal** | **NL** | **UK** | **Resc** | **Comments** |
| – | | | | | | | |
| **Endangered (EN) – 3** | **Criterion A2c** | **Criterion B1 (EOO)** | **Wal** | **NL** | **UK** | **Resc** | **Comments** |
| *Coccinella hieroglyphica* | VU [−32%] | EN [3087 km$^2$, a(i)b(ii,iii)] | r(−) | r | r(−) | No | |
| *Cynegetis impunctata* | LC [+240%) | EN [2173 km$^2$, a(i)b(iii)] | – | r | – | No | |
| *Exochomus nigromaculatus* | VU [−33%] | EN [3210 km$^2$, a(i)b(ii,iii)] | r(−) | r | – | No | |
| **Vulnerable (VU) – 6** | | | | | | | |
| *Adalia bipunctata* | EN [−57%, A2e] | NT [13 340 km$^2$, b(ii,v)] | c(−) | c | c(−) | Yes | Downgraded (rescue effect) |
| *Chilocorus bipustulatus* | VU [−39%] | VU [7354 km$^2$, a(i)b(iii)] | r(−) | r | r(o) | No | |
| *Coccinella magnifica* | LC [−14%] | VU [5082 km$^2$, a(i)b(iii)] | r(−) | r | r(o) | No | |
| *Hippodamia tredecimpunctata* | LC [+45%] | VU [6839 km$^2$, a(i)b(iii)] | r(−) | r | r(o) | No | |
| *Myzia oblongoguttata* | VU [−31%] | NT [3087 km$^2$, b(ii)] | r(−) | r | r(o) | No | |
| *Platynaspis luteorubra* | LC [+47%] | VU [5104 km$^2$, a(i)b(iii)] | r(+) | r | r(o) | No | |
| **Near Threatened (NT) – 7** | | | | | | | |
| *Anisosticta novemdecimpunctata* | LC [+4%] | NT [11 067 km$^2$, b(iii)] | r(+) | r | c(−) | No | |
| *Aphidecta obliterate* | NT [−27%] | NT [8934 km$^2$, b(ii)] | c(+) | c | c(o) | Yes | Downgraded (rescue effect) |
| *Coccinula quatuordecimpustulata* | LC [−10%] | NT [4552 km$^2$, b(iii)] | r(+) | r | – | No | |
| *Harmonia quadripunctata* | NT [−24%] | NT [9685 km$^2$, b(ii)] | r(o) | r | r(o) | No | |
| *Henosepilachna argus* | LC [+125%] | NT [5075 km$^2$, a(i)] | r(−) | r | r(o) | No | |
| *Myrrha octodecimguttata* | LC [+42%] | NT [7984 km$^2$, a(i)] | r(+) | r | r(o) | No | |
| *Subcoccinella vigintiquatuorpunctata* | NT [−22%] | NT [5842 km$^2$, b(ii,iii)] | r(−) | r | c(+) | No | |
| **Least Concern (LC) – 15** | | | | | | | |
| *Adalia decempunctata* | LC [−14%, A2e] | NT [11 992 km$^2$, b(v)] | c(o) | c | c(−) | Yes | Downgraded (rescue effect) |
| *Anatis ocellata* | LC [−14%] | LC [9968 km$^2$] | c(−) | c | c(o) | No | |
| *Calvia decemguttata* | LC [−19%] | LC [10 918 km$^2$] | c(+) | r | – | Yes | Downgraded (rescue effect) |
| *Calvia quatuordecimguttata* | LC [+11%, A2e] | NT [12 853 km$^2$, b(v)] | c(o) | c | c(−) | Yes | Downgraded (rescue effect) |
| *Chilocorus renipustulatus* | LC [+38%] | LC [11 351 km$^2$] | c(+) | c | c(o) | Yes | Downgraded (rescue effect) |
| *Coccinella quinquepunctata* | LC [+23%] | LC [11 860 km$^2$] | c(+) | r | r(o) | Yes | |
| *Coccinella septempunctata* | LC [+23%] | LC [13 750 km$^2$] | c(o) | c | c(o) | Yes | |
| *Coccinella undecimpunctata* | NT [−21%] | LC [11 633 km$^2$] | r(−) | c | c(−) | Yes | Downgraded (rescue effect) |
| *Exochomus quadripustulatus* | LC [+13%, A2e] | NT [12 930 km$^2$, b(v)] | c(+) | c | c(+) | Yes | Downgraded (rescue effect) |
| *Halyzia sedecimguttata* | LC [+17%, A2e] | LC [13 425 km$^2$, b(v)] | c(+) | c | c(+) | Yes | |
| *Hippodamia variegate* | LC [−14%] | LC [11 673 km$^2$] | c(+) | r | r(o) | Yes | Downgraded (rescue effect) |
| *Oenopia conglobata* | LC [+5%, A2e] | LC [12 091 km$^2$, b(v)] | r(−) | c | – | Yes | Downgraded (rescue effect) |
| *Propylea quatuordecimpunctata* | LC [−16%, A2e] | NT [13 737 km$^2$, b(v)] | c(o) | c | c(−) | Yes | Downgraded (rescue effect) |
| *Psyllobora vigintiduopunctata* | LC [+17%] | LC [13 648 km$^2$] | c(o) | c | c(−) | Yes | |
| *Tytthaspis sedecimpunctata* | LC [−4%] | LC [12 491 km$^2$] | c(+) | c | c(o) | Yes | Downgraded (rescue effect) |
| **Data Deficient (DD) – 3** | | | | | | | |
| *Calvia quindecimguttata* | | | | | | | |
| *Oenopia impustulata* | | | | | | | |
| *Vibidia duodecimguttata* | | | | | | | |
| **Not Evaluated (NE) – 3** | | | | | | | |
| *Adalia conglomerata* | | | | | | | |
| *Harmonia axyridis* | | | | | | | |
| *Hippodamia undecimnotata* | | | | | | | |

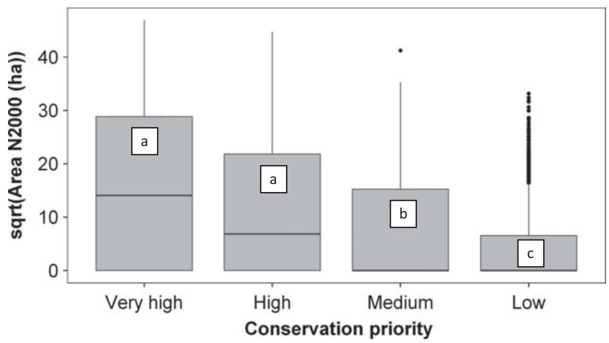


**Fig. 3.** Mean area of Natura2000 sites per grid cell with a very high (extinction risk value ≥85, $n = 95$), high (extinction risk value 65–84, $n = 93$), medium (extinction risk value 35–64, $n = 334$) and low conservation priority (extinction risk value ≤34, $n = 3689$). Different letters indicate significant differences among conservation priority categories.

relative change in distribution area as a population trend in the highest possible resolution, i.e. 1 × 1 km$^2$ grid cells.

Three species were considered as DD for various reasons. *Calvia quindecimguttata* (Fabricius 1777) is only known from one specimen collected in 1879 and was also reported in the vicinity of Brussels (Bouillon, 1859; Bovie, 1897), but the species has not been observed since, despite targeted surveys at suitable sites. *Oenopia impustulata* (Linnaeus 1767) has only been observed in relatively recent years, with some scattered records in the 1980s and 1990s (Ziegler & Teunissen, 1992). The most recent observation of this species dates from 2005 but the known locations were not revisited since (Bogaert & Beuckx, 2004). It is, therefore, unknown if the species is either extremely rare or RE. *Vibidia duodecimguttata* (Poda 1761) was observed for the first time in Flanders as recently as 2010 in a coastal dune reserve. In the south of Belgium, this thermophilous species is mainly confined to areas with calcareous grasslands.

When classifying ladybirds into Red List categories, criterion A (population trend) determined the highest Red List classification for only one species [*Adalia bipunctata* (L.), a widely distributed species but strongly declining after the arrival of the Harlequin ladybird – Roy *et al.*, 2012]. Criterion B (geographic range) determined the highest classification for ten species and for five species both criterion A and B resulted in the same Red List classification (cf. Cardoso *et al.*, 2012).

Compared with other Red Lists of invertebrates in Flanders, the percentage of threatened (CR, EN and VU) ladybird species (24%) is very similar to that of water bugs (23% – Lock *et al.*, 2013), butterflies (26% – Maes *et al.*, 2012) and dragonflies (27% – De Knijf *et al.*, 2006). The few Red Lists of ladybirds elsewhere in Europe have between 5% (Norway) and 30% (both Germany as a whole and the federal state of Bavaria – Table 4) of indigenous ladybird species on the regional Red Lists with a threat category. Nonetheless, not all of these Red Lists were compiled using the IUCN criteria, but instead used expert opinions to classify ladybirds in the different Red List categories and are, therefore, not comparable to the Red List we compiled for Flanders.

### *Traits explaining ladybird threats in Flanders*

Threatened ladybirds in Flanders are mostly confined to rare biotopes such as dry heathlands, nutrient-poor dry or wet grasslands, marshes, etc. Most threatened species display specific life history traits such as habitat and/or dietary specialisation or myrmecophily (cf. Desender *et al.*, 2010; Jeppsson & Forslund, 2014). The most important threats to ladybirds in Flanders are habitat loss, decreasing habitat quality (e.g. due to a very high nitrogen deposition) and habitat fragmentation (Zaviezo *et al.*, 2006). *Coccinella hieroglyphica* L. and *Exochomus nigromaculatus* (Goeze 1777) are both specialist species of wet and/or dry heathlands, a rare and threatened biotope in Flanders (Van Landuyt, 2002). In addition, *C. hieroglyphica* is a diet specialist feeding mainly on larvae of the chrysomelid *Lochmaea suturalis* Thomson (Hippa *et al.*, 1982) which typically shows boom and bust cycles (Blankwaardt, 1977). *Cynegetis impunctata* (Linnaeus

**Table 4.** Total number of species, number of extinct and threatened larger ladybirds (Red List categories *Critically Endangered*, *Endangered* and *Vulnerable*) in other European countries or regions.

| Country or region | Total | Extinct | Threatened | %Threatened | References |
|---|---|---|---|---|---|
| Flanders (N Belgium) | 36 | 2 | 9 | 25 | This paper |
| Wallonia (S Belgium) | 36 | 2 | 10 | 28 | San Martin y Gomez *et al.* (2006) |
| Great-Britain | 27 | – | 4* | 15 | Roy *et al.* (2011a) |
| Norway | 38 | – | 2 | 5 | Ødegaard *et al.* (2010) |
| Germany | 44 | – | 13 | 30 | Geiser (1998) |
| Bavaria | 43 | – | 13 | 30 | Schmidl and Esser (2003) |
| Sachsen-Anhalt | 40 | 1 | 8 | 18 | Witsack *et al.* (2004) |
| Schleswig-Holstein | 34 | 1 | 9 | 26 | Gürlich *et al.* (1995) |

*Species listed in the Conservation Designations for UK Taxa of the Joint Nature Conservation Council (http://jncc.defra.gov.uk/page-3408).

1767) is very rare in Flanders, although the species can be locally abundant. This phytophagous species is found both in hygrophilous habitat feeding on a range of different grass species (e.g. *Phalaris arundinacea* L., *Glyceria maxima* Holmberg and *Arrhenatherum elatius* L.) as well as in drier vegetation where it was found feeding on *Calamagrostis epigejos* Roth and *Holcus mollis* L. The species is wingless (Kuznetsov, 1997) and its limited dispersal capacity might explain its regional rarity. Examples of specialist myrmecophilous species are the obligate *Coccinella magnifica* Redtenbacher 1843, *Platynaspis luteorubra* (Goeze 1777) and the facultative myrmecophilous ladybird species *Myzia oblongoguttata* L.. Myrmecophily is often linked with behavioural, defensive or physical traits (Sloggett *et al*., 2002; Sloggett & Majerus, 2003; Vantaux *et al*., 2012). The myrmecophily of these species, categorised as VU, certainly adds to the complexity of ecosystems (cf. Thomas *et al*., 2005, 2009). The larvae of *Platynaspis luteorubra* primarily feed on ant-tended aphids (Volkl, 1995). The habitat of this thermophilic species in Belgium consists, to a large extent, of lawns and grasslands with sparse vegetation structure. This type of habitat is relatively common (Dekoninck *et al*., 2004), but its obligate association with *Lasius niger* L. ants may be a reason for the current rarity of the species.

Due to their economic significance as biocontrol agents, there has been considerable movement of coccinellids worldwide and the proportion of alien species for this group is relatively high in Europe (Roy & Migeon, 2010). Several species occurring in the wild in Belgium are actually non-native and were not evaluated for this Red List. This is the case for *H. axyridis* which is considered invasive in its European range (Adriaens *et al*., 2003, 2008). Other non-native species are the Australian mealybug predator *C. montrouzieri* of which a single specimen from the year 1957 is present in a Belgian museum collection (unpubl. data) and the Australasian coccid predators *R. forestieri* (Bogaert, 2008) and *R. lophanthae* (Van den Heuvel, 1988). The latter three species are currently only incidental species in Belgium. *Hippodamia convergens* Guerin-Meneville 1842 has also been released in Belgium, but this species has not been reported in the wild so far (Roy & Migeon, 2010).

### *Policy and conservation*

A Red List assessment is a prerequisite for compiling species protection plans in Flanders (Flemish Government Decision of 15/05/2009 on species protection and species management). Apart from extinction risk, setting conservation priorities should also take other factors (ecological, functional and pragmatic) into account (Rodrigues *et al*., 2006). Although threatened species deserve conservation priority because they can disproportionately increase the potential breadth of functions provided by ecosystems across spatial scales (Mouillot *et al*., 2013), non-threatened species should also receive appropriate attention as potential biological control agents. In Flanders, there is a fairly strong separation between (semi-)natural areas and unsuitable areas (urban areas, intense agricultural land) and, therefore, the overlap of hotspots among different species groups (especially fauna) is relatively high (Maes *et al*., 2005). Most of the ladybird hotspots are located in the Campine region in the northeast of Flanders (Fig. 2). This sandy region has a warmer microclimate than the rest of Flanders and holds most of the large heathlands, marshes and nutrient-poor grasslands with its typical and threatened ladybird fauna. Agricultural areas can play an important role in mediating ladybird populations through spillover effects between intensively managed and natural habitats (Blitzer *et al*. 2012). This is especially true for the generalist species *Coccinella septempunctata* L., *Propylea quattuordecimpunctata* (L.), *Hippodamia variegata* (Goeze 1777) and the invasive alien *H. axyridis* that frequently occur on crops in Belgium (Vandereycken *et al*., 2013b). In potato, aphids are an important food source for at least three species: *C. septempunctata*, *P. quatuordecimpunctata* and *A. bipunctata* (Jansen & Hautier, 2008). In broad bean cropland, a less common crop in Flanders, ladybirds can dominate the aphidophagous guild (Vandereycken *et al*., 2013a).

Comprehensive conservation measures for ladybirds, however, are scarce. Yet, the maintenance of a variety of typical ladybird habitats such as wetlands, grasslands and heathlands with warm microclimates is of major importance. Urban and suburban environments can also typically be very rich in ladybirds, both in terms of species numbers and abundance (Brown *et al*., 2011; N. Ottart, G. San Martin y Gomez, unpubl. data). Here, attention could be paid to (relict) populations of a near threatened habitat specialist such as *Henosepilachna argus* (Geoffroy 1762). Also, in public greenery, the use of native plant species and trees that are of value to ladybirds at some stage of their life cycle (food plant, host plants of aphids, overwintering) can generally be beneficial to ladybirds. The choice of tree species for plantings in an urban environment is crucial here. Often, authorities choose non-native trees that perform well with respect to the particularities of the city (soil compaction, air quality, resistance to aphid outbreaks). These are, however, not always beneficial for native ladybirds. Also, in borders, roadside plantings and public greenery, perennial plants (e.g. tussock forming grasses) offer more valuable microhabitats to ladybirds for feeding or overwintering. Less intensive management, for example, avoiding disturbance of ground cover in winter, can provide shelter for overwintering ladybirds. Likewise, at a smaller scale, the same strategy can be applied to private gardens (Majerus, 1994a). Common nature management practices could take the presence of ladybirds into account. Avoiding homogeneous habitats, rotational mowing regimes and creating vegetation gradients along woodlands are well known measures that favour many groups of invertebrates (Lovei *et al*., 2006). Of particular concern are situations where conflict might arise with management solely aimed at enhancing botanical diversity which could negatively impact invertebrate communities. Intensive grazing, for example, can be detrimental to ladybirds that are associated with ants (Adriaens *et al.*, 2005). In heathlands, the diversity of invertebrate assemblages relies on habitat complexity (Usher & Thompson, 1993). Heathland management (e.g. mowing, burning) aimed at a uniformous and even-aged heather vegetation has, therefore, little added value for ladybirds. This is especially true for the endangered heathland specialist species *C. hieroglyphica* and *E. nigromaculatus*, which prefer old diversified heathland with shrub and young trees in Belgium (San Martin y Gomez & Verté, 2004). In agricultural areas, long-term set-aside sites can be a good measure for ladybirds. Furthermore, in crops, integrated pest management can be applied, limiting the use of insecticides with low direct lethal or sublethal effects on natural enemies such as ladybirds (Galvan *et al.* 2005). In forestry practices, leaving out some of the non-native Scots pine *Pinus sylvestris* L. can be in favour of pine inhabiting species (Majerus, 1994a). Several options have been suggested for mitigating the impact of the invasive alien *H. axyridis* on native ladybird species but a good method to do this at a landscape scale is currently lacking (Kenis *et al.*, 2008). To prevent non-target impacts of non-native ladybirds, biocontrol releases should be subject to a thorough risk assessment (van Lenteren *et al.*, 2008).

Climate change might have a positive effect on species of warm microclimates such as particular ladybirds. The importance of climate, particularly microclimate, to coccinellid development and behaviour has been demonstrated in a number of studies, but these mostly relate to crop habitats (Ewert & Chang, 1966; Smith, 1971; Honek, 1979). In natural habitats, coccinellids might be better able to adapt to changing climatic conditions. Ladybirds are known to exhibit phenotypic plasticity and most species have good dispersal capacities (Majerus, 1994b). This buffers these species against some of the detrimental effects of changing climatic factors provided that barriers to their dispersal are absent and favourable habitat is available. It is generally acknowledged that climate change can act synergistically to other threat factors such as habitat loss and fragmentation (Brook *et al.*, 2008). Warmer climates might allow species to expand their range, as has been noted for butterflies and dragonflies (Hickling *et al.*, 2005), but these benefits can be outweighed by other threats such as habitat modification (Warren *et al.*, 2001), invasive species (Dukes & Mooney, 1999; Roy *et al.*, 2012) or microclimatical cooling (WallisDeVries & van Swaay, 2006). Moreover, the relationship between coccinellids and climatic factors are complex, varying temporally and spatially, and with life stage (Roy & Majerus, 2010). Direct empirical evidence that ladybirds will be negatively affected by climate change is sparse. For some species (e.g. mildew feeders) the effect might be positive, mediated by an increased food availability. For overwintering ladybirds, however, increased fluctuations in winter temperatures due to climate change may lead to increasing rates of winter mortality in species with an obligatory diapause (Roy & Majerus, 2010). It is, therefore, probable that stenotopic specialist species confined to cold habitats, such as bogs and fens [e.g. *Hippodamia septemmaculata* (DeGeer 1775)] might be negatively affected by climate change as has been shown with other insect groups (e.g. butterflies – Turlure *et al.*, 2010). Furthermore, climate change can induce a phenological mismatch between predatory ladybirds and peak abundance in their preferred prey inducing increased levels of cannibalism and intraguild predation and thereby reducing ladybird numbers (Roy & Majerus, 2010). Climate change may also affect host–parasite interactions (Brooks & Hoberg, 2007). Ectoparasitic mites, entomopathogenic fungi, protozoa, endoparasitic nematodes, male-killing endosymbionts, dipteran and hymenopteran parasitoids are prevalent natural enemies of coccinellids (Riddick *et al.*, 2009) and it has been suggested that some of these can mediate the relative success of species (Roy *et al.*, 2011b; Comont *et al.*, 2013; Vilcinskas *et al.*, 2013). Also, entomopathogens of aphids are known to influence the aphid guild (Roy *et al.*, 2008). Nevertheless, whether changes in host–parasite interactions due to climate change could result in population level or range size effects is unclear.

In conclusion, the application of the IUCN Red List criteria (at least criteria A and B) was shown to be feasible for ladybirds in Flanders using the highest spatial resolution available (here, $1 \times 1$ km$^2$) to calculate distribution changes. To avoid an underestimation of the geographical range of ladybird species in Flanders, we preferred to use the EOO as a measure of geographical range rather than area of occupancy. As we could only assess species against two criteria because data on population numbers were unavailable, the trends are to be regarded as a conservative assessment of the actual threat status. The Red List also allowed the determination of regional ladybird hotspots for which adequate management and conservation and policy measures can be proposed. The method proposed here could also be applied to other relatively less-surveyed groups for which comparable data sets exist in the region (e.g. Dytiscidae, Syrphidae, Araneae).

## Acknowledgements

First of all, we would like to thank the many volunteers of the Belgian ladybird working group and other observers who collected the distribution data for this analysis. We thank Koen Lock for collecting old publications on ladybirds in Belgium. We thank Natuurpunt for making the observations of www.waarnemingen.be available. We are grateful to Frederic Piesschaert for data handling. We thank Axel Vandereycken for information on ladybirds in Belgian crop systems. We thank three anonymous reviewers for their careful reading of our manuscript and their insightful comments and suggestions.

## Supporting Information

Additional Supporting Information may be found in the online version of this article under the DOI reference: doi: 10.1111/icad.12124:

**Figure S1.** Ecological districts (upper map) and ecoregions (lower map) in Flanders that were used to calculate the EOO (based on Couvreur et al. 2004). Ecodistricts are homogeneous spatial entities with respect to abiotic characteristics. On a higher hierarchical level, ecodistricts are grouped into ecoregions (colour legend with numbers referring to ecodistricts) based on geological and geomorphological similarity.

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Accepted 17 February 2015

Editor: Calvin Dytham
Associate editor: Allan Watt