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BEETLE CONSERVATION

# The decline of native coccinellids (Coleoptera: Coccinellidae) in the United States and Canada

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**Abstract** Reviewing published coccinellid surveys we found that the number of adventive species has increased steadily over the last century while the average proportion of native individuals has remained fairly constant until 1987 followed by a rapid decrease between 1987 and 2006. Seven long-term studies indicated that the total density of coccinellids increased by an average of 14% following establishment of adventive species, but this increase was not significant and in 4 of 7 cases the total density of coccinellids actually decreased following establishment. Similarly, no significant difference was found in comparisons of diversity across all studies. These results illustrate that even with multiple long-term data sets it is currently difficult to make any general conclusions regarding the impact adventive coccinellids have had on native coccinellid assemblages. However, it is clear that specific systems and species have seen major shifts in recent years. For example, adventives have become the dominant species in a third of the assemblages where they are found. Focusing on two formerly common native species, *Adalia bipunctata* and *Coccinella novemnotata*, we show they have become rare in their former ranges and discuss potential explanations for this phenomenon.

**Keywords** *Adalia* · *Coccinella* · Adventive species · Ladybirds · Aphids

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## The importance of coccinellid diversity and abundance

Coccinellids, known as ladybugs, ladybeetles, or ladybird beetles are one of the most common and easily recognizable invertebrate components of almost every terrestrial ecosystem in the US and Canada (Gordon 1985). Species in this family are so ubiquitous and yet so sensitive to environmental conditions that they have been proposed as indicator species (Iperti 1999).

This species complex also contributes to the regulation of many soft-bodied insects, especially those in the order Homoptera, and is valuable in controlling the egg and larval stages of other insects (reviewed in Hodek and Honěk 1996). The services that these predators provide are so well recognized and respected that pest management practices are often designed to take advantage of their pest suppression potential. For example, in alfalfa the decision to take action to suppress aphid populations is based on both aphid and coccinellid densities (e.g., Knowles 2006). Pesticides are not applied even if aphid densities exceed what would be economically damaging levels if the density of coccinellids is high enough to suppress them.

Given their potential to control pest species, many programs have tried to supplement extant populations or introduce new species. Purchasing and releasing natural enemies to augment biological control is a potentially valuable and continually growing practice with coccinellids being one of the most important groups used (Cranshaw et al. 1996). Vast resources have also been expended to introduce and permanently establish coccinellid species that are not native to the Nearctic region. One of the first successes with classical biological in the US involved importing the vedalia beetle, *Rodalia cardinalis*, from Australia to suppress

the cottony cushion scale, *Icerya purchasi*, in California. The entire cost of this project is estimated at $2,000 (Pedigo and Rice 2006), approximately $41,000 in 2005 adjusting for inflation. This figure is probably below the average cost of subsequent introductions given the increased level of pre-release research that is usually done. Taking the adjusted figure as an average cost for the 179 coccinellid introductions into North America (Gordon 1985) the total cost of these efforts exceeds 7 million dollars.

Given their charisma and acknowledged importance, it is not surprising that numerous studies have examined the composition of this complex and a smaller but no less important body of literature has related their density and diversity to ecological function. Two clear emergent properties are that coccinellid species vary widely in the level of suppression they exert on various prey species (reviewed in Hodek and Honěk 1996) and that species vary widely in their response to environmental changes (Iperti 1999; Bazzocchi et al. 2004). Thus, long-term regional shifts in species composition may have important implications for the functioning of this complex and its response to environmental changes. In this paper we draw on published surveys to examine the density and composition of aphidophagous coccinellids in the US and Canada over the past hundred years.

## Materials & methods

We reviewed the published literature for surveys of adult aphidophagous coccinellids in natural and managed ecosystems throughout the United States and Canada. Despite the importance of a number of coccidophagous coccinellids for biological control in North America, e.g., *Rodolia cardinalis* (DeBach 1964), we focus here on aphidophagous species due to their ubiquitous nature, their dominance in the literature, and their importance in recent purposeful and accidental invasions. Studies were included if there were at least 20 naturally occurring individuals collected, the proportion of native and adventive species was easily determined from the paper, and >95% of individuals were identified to species. Only a very small number of studies included larval information, so for consistency we only used information on adult coccinellids. We extracted multiple data sets if collections were made in distinct large-scale habitats (e.g., two different crops) or if multi-year studies had distinct sampling periods with considerable differences (e.g., before and after an invasion). We determined the average coccinellid assemblage for all other multiyear surveys by calculating the proportion of each species in the assemblage for each year and then averaging across years. For analyses over time we used the midpoint date (rounded up) for these multiyear surveys. We also determined average assemblages in the same manner when surveys took place across multiple but similar habitats (e.g., multiple fields of the same crop). Note that in a few instances (e.g., Putnam 1964) information was not available to calculate the average assemblage in this way and we were forced to use an average assemblage as determined by the author. These criteria resulted in information on 71 coccinellid assemblages from 36 references (Ewing 1914; Fluke 1925; Dobzhansky 1935; Fenton and Howell 1955; Godarzy and Davis 1956; Smith 1958; Putnam 1964; Day 1965; Gagne and Martin 1968; Smith 1971; Wheeler 1971; Watve and Clower 1976; Angalet et al. 1979; Turnock and Turnock 1979; Lee 1980; Dowell and Cherry 1981; Mareida et al. 1992; Elliott et al. 1996; LaMana and Miller 1996; Colunga-Garcia et al. 1997; Hoffmann et al. 1997; Brown and Miller 1998; Colunga-Garcia and Gage 1998; Boiteau et al. 1999; Cormier et al. 2000; Hesler et al. 2000; Wright and DeVries 2000; Wold et al. 2001; Bosque-Perez et al. 2002; Stephens 2002; Brown 2003; Turnock et al. 2003; Alyokhin and Sewell 2004; Evans 2004; Hesler et al. 2004; Musser et al. 2004). We further calculated measures of species richness, the Berger–Parker Dominance Index, as well as Simpson's D and Shannon's H diversity indices for the 62 data sets in which all collected individuals were identified to species (Magurran 1988). Since both diversity indices gave very similar results, we only report Simpson's D here.

## Results and discussion

### Establishment and increase of adventive species

It is difficult to discuss the status of native species without also considering the data on adventive species. The evidence for a causal relationship between the establishment of adventive species and the decline of native species is by no means conclusive (as we discuss below). However, they have certainly changed the composition of this complex by their presence alone.

At least 179 coccinellid species have been introduced deliberately or inadvertently and 27 have become established in the US and Canada (Fig. 1) (Gordon 1985; Gordon and Vandenberg 1991). It appears that although the establishment of many species has been confirmed, very few have grown to levels where they are commonly found in published surveys.