

## Bad side of a good beetle: the North American experience with *Harmonia axyridis*

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**Abstract** The multicolored Asian lady beetle, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) is a generalist predator of aphids and other soft-bodied insects and has been utilized in biological control programs around the world. Over the last two decades, this species has spread throughout much of the continental USA and southern Canada. Despite the benefits it offers as a biological control agent, *H. axyridis* is perhaps most well known for its adverse impacts. In this paper we provide a review of the North American experience with *H. axyridis*, focusing on these adverse impacts, which can be classified into three general categories: impacts on non-target arthropods, impacts on fruit production and impacts as a household invader. The impacts of *H. axyridis* on non-target arthropods and, to lesser extent, the impacts as a household invader possibly could have been anticipated, due to its generalist feeding preferences and overwintering behavior in Asia. However, it is unlikely that the impacts on fruit production could have been anticipated. Therefore, even in retrospect, it is difficult to predict the potential impacts that an introduced natural enemy might have in its adventive range.

**Keywords** Biological control · Coccinellidae · Coleoptera · Invasive species

### Introduction

“Hordes of maddening ladybugs headed this way” (Gerhardt 2000). “They’re everywhere! They’re everywhere!” (Fortune 2000). “Steroid Asian lady beetles move into town” (Koehler 2002). These are titles of newspaper articles referring to the invasion and impacts of the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas) (Coleoptera:

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Coccinellidae), in North America. This semi-arboreal coccinellid is a generalist predator of aphids and other soft-bodied arthropods (Hodek and Honěk 1996; Koch 2003). In its native Asian range, *H. axyridis* is a voracious predator of various pest species (Yasumatsu and Watanabe 1964; Hodek and Honěk 1996). Because of this biological control potential, *H. axyridis* has been utilized as a biological control agent in various locations around the world. Intentional releases for biological control purposes (e.g., Gordon 1985) coupled with potential unintentional introductions via international trade (Day et al. 1994; Roy et al. 2005) contributed to the expansion of its range to include North America (Chapin and Brou 1991; Coderre et al. 1995; Dreistadt et al. 1995), South America (Almeida and Silva 2002; Saini 2004), Europe and Africa (Brown et al. 2007).

Koch et al. (2006c) provide a detailed review of the invasion history of *H. axyridis* in North America. Releases in North America for biological control date back to 1916, with more intensive releases in 1970s and 1980s (Gordon 1985; Tedders and Schaefer 1994; LaMana and Miller 1996). Established populations in North America were first detected in Louisiana in the southeastern USA in 1988 (Chapin and Brou 1991). Despite the well documented releases of *H. axyridis* in North America, it has been argued that these early populations resulted from unintentional introductions via international commerce rather than the documented intentional releases for biological control (Day et al. 1994; Day and Tatman 2006). Currently, it remains unclear whether the North American populations stemmed from intentional or unintentional introductions or a combination of both (e.g., Krafstur et al. 1997). Regardless of the source of these initial populations, the range of *H. axyridis* expanded rapidly to cover much of the continental USA and southern Canada (Koch et al. 2006c). In addition, populations have been detected in Mexico (Koch et al. 2006c). The rate of range expansion was estimated to be 442 km per year (McCorquodale 1998) and suggested to be greater in areas with more arboreal habitat (Hesler et al. 2004) or with biomes more similar to those of its native range (Koch et al. 2006c). However, such estimates may be confounded by various factors, such as potential undocumented releases and varying levels of sampling intensity (Koch et al. 2006c).

Beneficial impacts of *H. axyridis* as a biological control agent have been observed in various systems and locations around the world (Koch 2003; Pervez and Omkar 2006). In North American pecans, *H. axyridis* is a successful biological control agent for the pecan aphid complex (*Monellia caryella* (Fitch), *Moneliopsis pecanis* Bissel and *Melanocallis caryaefoliae* (Davis)), which was the target for some of the early releases of this predator (Tedders and Schaefer 1994; LaRock and Ellington 1996). This predator now occurs in and may be contributing to pest suppression in various agricultural and natural systems in North America (Colunga-Garcia and Gage 1998; Koch 2003; Nault and Kennedy 2003; É. Lucas, personal communication). For example, this predator appears to be an important natural enemy of *Aphis glycines* Matsumura, an invasive soybean pest in North America (Fox et al. 2004; Rutledge et al. 2004; Fox et al. 2005; Costamanga and Landis 2006; Mignault et al. 2006). *Harmonia axyridis* has also been documented preying on *A. glycines* on its overwintering host, *Rhamnus cathartica* L., in autumn (Hesler et al. 2004).

However, like other exotic natural enemies that have had some negative impacts after establishment (Howarth 1991; Simberloff and Stiling 1996; Louda et al. 2003), *H. axyridis* is showing adverse impacts in its adventive range (Koch 2003). In this paper we provide a review of the North American experience with *H. axyridis*, focusing on its adverse impacts. These impacts can be classified into three general categories: impacts on non-target arthropods, impacts on fruit production and impacts as a household invader. Could such impacts have been anticipated?

## Impacts on non-target arthropods

### Intraguild impacts

*Harmonia axyridis* has become a prominent member of the generalist predatory guild in many of the agricultural (Brown and Miller 1998; Colunga-Garcia and Gage 1998; Michaud 2002; Nault and Kennedy 2003; Alyokhin and Sewell 2004; Koch et al. 2006a; Hesler et al. 2004; Musser et al. 2004; Park and Obrycki 2004; É. Lucas, personal communication) and natural habitats (Wallace and Hain 2000; Sebolt and Landis 2004) it has invaded in North America. The establishment of *H. axyridis* alone, or sometimes in combination with other exotic coccinellids (e.g., *Coccinella septempunctata* L. and *Propylea quatordecimpunctata* (L.)), has been associated with a numerical and/or proportional decline of some native coccinellid species in apple orchards (Brown and Miller 1998), citrus groves (Michaud 2002), potato fields (Alyokhin and Sewell 2004), and across an agricultural landscape (Colunga-Garcia and Gage 1998). In contrast, the replacement of the previously established *C. septempunctata* with *H. axyridis* as the most abundant coccinellid in apple orchards may have actually increased the abundance of some native coccinellids (Brown 2003). Harmon et al. (2007) recently highlighted the dramatic decline of *Adalia bipunctata* (L.) over a broad geographic range after the invasion of *C. septempunctata* and *H. axyridis*. However, it has been pointed out that such correlations from observational studies do not demonstrate causality (Day and Tatman 2006; Harmon et al. 2007). Despite dramatic system and species-specific cases such as *A. bipunctata*, analyses of multiple long-term data sets were not able to show a significant general adverse effect of exotic coccinellids on populations of native coccinellids in the USA and Canada (Harmon et al. 2007). Potential impacts on populations of guild members other than coccinellids have received little attention. Brown (2003) found no decrease in the abundance of *Aphidoletes aphidomyza* Rondani or various Chrysopidae after the establishment of *H. axyridis*.

The success of *H. axyridis* in North America has been attributed to various factors (e.g., Michaud 2002; Snyder et al. 2004; Yasuda et al. 2004; Shapiro-Ilan and Cottrell 2005; Labrie et al. 2006). Among the factors potentially contributing to the rapid rise to dominance of *H. axyridis* over native species, intraguild predation has been most intensively studied in North America. Intraguild predation involves predation among individuals of the same trophic level (Rosenheim et al. 1995). As mentioned by Yasuda et al. (2004), the intraguild predator gains direct nutritional benefits and indirect benefits through reducing competition (Dixon 2000). In such interactions, *H. axyridis* generally dominates (Koch 2003). Native predators (i.e., coccinellids and chrysopids) generally exhibit lower rates of predation on *H. axyridis* eggs compared to the predation rates of *H. axyridis* on the eggs of native species (Phoofolo and Obrycki 1998; Cottrell 2004, 2005; Flowers et al. 2005). *Harmonia axyridis* larvae are relatively larger and more aggressive than larvae of native coccinellids (Cottrell and Yeorgan 1998; Michaud 2002; Yasuda et al. 2004). When paired with heterospecific coccinellid larvae of the same size or smaller than itself, *H. axyridis* larvae are generally intraguild predators (Cottrell and Yeorgan 1998; Yasuda et al. 2004). However, when paired with a heterospecific larva considerably larger than itself, *H. axyridis* larvae may be intraguild predators (Michaud 2002) or prey (Cottrell and Yeorgan 1998). Snyder et al. (2004) found no relationship between size advantage and intraguild predation rates. They suggest that the success of *H. axyridis* as an intraguild predator of native coccinellids may be due to greater abilities to capture intraguild prey and avoid and escape intraguild predators (Snyder et al. 2004). *Harmonia axyridis* has been

documented feeding on various stages of North American predatory species, such as *A. bipunctata* (Sato et al. 2005), *C. septempunctata* (Snyder et al. 2004; Yasuda et al. 2004), *Coccinella transversoguttata* Falderman (Snyder et al. 2004; Yasuda et al. 2004), *Coleomegilla maculata* DeGeer (Cottrell and Yeargan 1998; Cottrell 2004, 2005), *Cycloneda sanguinea* (L.) (Michaud 2002), *Hippodamia convergens* Guérin-Méneville (Snyder et al. 2004; Yasuda et al. 2004), *Laricobius nigrinus* Fender (Flowers et al. 2005), *Olla v-nigrum* Mulsant (Cottrell 2004, 2005), *Sasajiscymnus tsugae* Sasaji and McClure (Flowers et al. 2005), *Chrysoperla carnea* Stephens (Phoofolo and Obyrcki 1998; Gardiner and Landis 2007), and *A. aphidomyza* (Gardiner and Landis 2007). Not only is this predator known to feed on these various prey, it can complete development feeding on some of them (Cottrell and Yeargan 1998; Michaud 2002; Cottrell 2004).

The presence of an intraguild predator can disrupt pest suppression in some systems (Rosenheim et al. 1995). However, the presence of *H. axyridis* as an intraguild predator in a system does not necessarily result in reduced pest suppression (Brown and Miller 1998; Lucas et al. 2002; Gardiner and Landis 2007). For example, as mentioned above, *H. axyridis* is an important predator of *A. glycines* on soybean and an intraguild predator of *A. aphidomyza* and *C. carnea*. The high predation rate of *H. axyridis* on the pest appears to compensate for the resulting reduction in the abundance of other natural enemies (Gardiner and Landis 2007).

### Interguild impacts

Despite the paucity of literature on the topic, non-target prey of *H. axyridis* are not limited to other predators. It was suggested that *H. axyridis* may impact native, non-pest aphid species (Boettner et al. 2000). In prairie remnants, this predator was indeed found preying on native aphids (e.g., *Aphis monardae* Oestlund on *Monarda fistulosa* L. and *Aphis asclepiadis* (Fitch) on *Asclepias syriaca* L.) (K. Wyckhuys and R. Koch, unpublished data). In addition, Sebolt and Landis (2004) identified *H. axyridis* as a predator of the chryso-melid, *Galerucella californiensis* L., which is a weed biological control agent used in North American wetlands. They concluded that the predator complex including *H. axyridis* might reduce populations of the weed biological control agent, but would be unlikely to prevent its establishment (Sebolt and Landis 2004). Furthermore, Koch et al. (2003) documented *H. axyridis* preying on the eggs and larvae of a non-pest lepidopteran, the monarch butterfly, *Danaus plexippus* L. A quantitative risk assessment, combining the likelihoods of exposure (i.e., co-occurrence) and effect (i.e., predation), showed the potential for *H. axyridis* to adversely affect the production of *D. plexippus* in agricultural systems (Koch et al. 2006b). Continued development of such risk assessment methodologies will improve our understanding of the non-target impacts of exotic species such as *H. axyridis*.

It comes as little surprise to see an exotic natural enemy with such a broad host range having adverse impacts on non-target species (intraguild and interguild). In a biological control context, generalist feeding preferences can enable a natural enemy to persist on alternate prey during times when target prey are unavailable, thus potentially increasing the likelihood of biological control success. However, it is this same attribute that increases the likelihood of impacts on non-target species. A heightened awareness for the potential of generalist natural enemies to impact non-target species is driving the biological control community to develop rigorous methods for identification and evaluation of highly specific natural enemies, which have lower associated risk of impacting non-target species.

## Impacts as a household invader

Mass aggregations of coccinellids at overwintering sites are well documented (e.g., Hagen 1962; Sakurai et al. 1993; Majerus 1994; Nalepa et al. 1996; Kuznetsov 1997). *Harmonia axyridis* has shown hypsotactic aggregation behavior in Asia and North America, accumulating in cracks and crevices of mountain tops, rocks, houses, forest huts, barns, and other human-made structures (Obata 1986; Sakurai et al. 1993; Kidd et al. 1995; Nalepa et al. 1996; Kuznetsov 1997; Huelsman and Kovach 2004).

In the USA, the infamous autumn flight of *H. axyridis* to the aggregation sites has been studied by Nalepa et al. (2000, 2005). These authors suggested a five-step aggregation behavior for *H. axyridis*: (1) exodus from feeding locations, (2) arrival on buildings or mountaintops, (3) decision to stay or leave, (4) if staying, insects search for cracks or crevices, and (5) then settle in these places (Nalepa et al. 2000, 2005). In addition, *H. axyridis* also shows a preference for places with high color contrasts, and for flying during the day when temperatures are above 21°C (Nalepa et al. 2005). Observations from Ohio suggest that the flight begins in autumn on the first day with temperatures greater than 18°C just after a low temperature near 0°C (Huelsman et al. 2002). Beyond the annoyance caused by the sheer numbers of *H. axyridis* on and inside homes, infestations cause problems in houses by staining carpets, curtains, furniture, and the walls; additionally, in the food industry, and health and research institutions *H. axyridis* can be a contaminant pest (Riddick et al. 2000; Huelsman and Kovach 2004; Nalepa et al. 2004). In addition, *H. axyridis* will occasionally bite humans (Kuznetsov 1997; Kovach 2004). Furthermore, seasonal allergic reactions to the presence of *H. axyridis* in homes have been described in several case studies (Yarbrough et al. 1999; Ray and Pence 2004; Goetz 2007). Allergy types caused by infestations of this beetle are mainly allergic rhinoconjunctivitis, and less often asthma, urticaria (Goetz 2007) or angioedema (Davis et al. 2006).

Control of *H. axyridis* with insecticides in buildings and houses may be undesirable because of potential negative effects of pesticide exposure to humans and pets. In addition, this coccinellid is beneficial as a predator during the spring and summer. Therefore, methods based on volatile chemicals to repel *H. axyridis* from houses and buildings and to attract them to traps (i.e., “push-pull” strategy) have been examined (Riddick et al. 2000). Among the potential repellents tested, camphor and menthol have shown good results for repelling *H. axyridis* (Riddick et al. 2000). In addition to these two compounds, DEET (*N,N*-diethyl-3-methylbenzamide) has shown repellency to *H. axyridis* (Riddick et al. 2004). However, further work is needed to develop formulations suitable for exterior use on homes (Riddick et al. 2004). In Europe, the presence of some type of aggregation pheromone was suggested for guiding *A. bipunctata* to the same overwintering locations every year (Majerus 1997). Nalepa et al. (2000) suggest that *H. axyridis* does not rely on volatile chemical cues to locate overwintering locations. However, further work like that of Brown et al. (2006) is needed to explore the role of volatiles emitted by adult *H. axyridis*. In their study, they used gas chromatography–mass spectrometry to identify volatiles (e.g., a sesquiterpene, (-)- $\beta$ -caryophyllene) emitted by live adults (Brown et al. 2006).

The utilization of houses and other buildings is not unique to *H. axyridis*. *Adalia bipunctata* is known to overwinter in houses (Majerus and Kearns 1989). Furthermore, *C. septempunctata* became a nuisance pest during population explosions in 1952 and 1976 in England (Majerus and Kearns 1989). However, the magnitude and/or frequency of these problems are greater for *H. axyridis* than what has been reported for other species. It should not come as a surprise that *H. axyridis* is becoming a household nuisance pest in its adventive range, because this pest exhibits a similar behavior in parts of its native range

(Obata 1986; Kuznetsov 1997). Kuznetsov (1997) described this behavior: “Sometimes huge numbers of beetles accumulated in houses. They penetrate everywhere, settle on people and annoy them with slight pinching.”

## Impacts as a pest of fruit production

### Fruit feeding and contamination

*Harmonia axyridis* has been reported feeding on fruits, such as grapes, apples, peaches, plums, pears, pumpkins and raspberries, in North America (Hesler et al. 2004; Koch et al. 2004; Kovach 2004). The feeding behavior of *H. axyridis* switches from carnivory to phytophagy in a manner that is not completely understood. Whether *H. axyridis* is causing primary injury to the fruits (i.e., breaking the skin of fruit) or is feeding on fruits injured by other agents remains unclear for some fruit types. In Minnesota, *H. axyridis* adults were not able to cause primary injury to grapes, apples or pumpkins, but they could inflict primary injury to raspberries (Koch et al. 2004; T. Galvan, unpublished data). In contrast, Kovach (2004) reported that *H. axyridis* could cause primary injury to apples, peaches and grapes in Ohio. Whether or not this beetle is breaking the skin of the fruits themselves, they display a strong preference for previously damaged versus undamaged fruits (Koch et al. 2004; Kovach 2004). Consuming food of plant origin (i.e., pollen, nectar, and extrafloral nectaries) is not unusual in predatory Coccinellidae (Hemptinne and Desprets 1986; Hodek and Honěk 1996; Ricci and Ponti 2002). Such feeding increases the chances of survival when prey are scarce, raises reserve levels for overwintering, and may improve coccinellid fitness even when prey are available (Smith 1960; Hagen 1962; Hemptinne and Desprets 1986; Harmon et al. 2000). Frugivory (i.e., fruit feeding) in predatory coccinellids appears to be rare, but has been documented for *C. septempunctata* and *A. bipunctata* (Hodek and Honěk 1996). We are unaware of predatory Coccinellidae causing agricultural problems of economic importance, except for the recent case of *H. axyridis* on wine grapes in North America.

Adults of *H. axyridis* move to vineyards 2–3 weeks before harvest, which begins in early September in Minnesota and Wisconsin, when prey populations in summer crops decline (Galvan et al. 2006c). During this period the grape berries are nearing maturity and may be injured by other fruit feeders, including paper wasps, yellow-jackets, other wasps, and birds or physiological splitting, which is common in some varieties close to harvest (Galvan et al. 2006b). Splitting is caused by a sudden increase in absorption and/or adsorption of water, atmospheric humidity, or temperature (Opara et al. 1997). Varieties with a tight cluster structure tend to have high rates of splitting (T. Galvan, unpublished data). This previous damage offers accessible feeding sites for *H. axyridis*. Field studies showed a strong correlation between injured wine grape berries and *H. axyridis* infestations in grape clusters (Galvan et al. 2006b). Depending on the proportion of clusters with damage, *H. axyridis* populations can easily build to infest 65% of all clusters for some varieties (Galvan et al. 2006b).

We hypothesize that *H. axyridis* feeds on grapes and other fruits in autumn to build reserves for overwintering. A couple months prior to overwintering, coccinellids start to prepare for winter by a mechanism called pre-diapause, where beetles accumulate fat and glycogen reserves, which is triggered by a decline in food resources (Hagen 1962; Hodek and Čerkasov 1963; Hodek 1986). The combination of these environmental and physiological changes, which has been called the “adaptation syndrome” (de Wilde 1970), in the



months preceding winter contributes to coccinellid survival during diapause (Hagen 1962; Hodek and Čerkašov 1963). Koch et al. (2004) confirmed a highly significant preference for sugar water versus water alone, which suggested that the beetles may be seeking more than just a source of moisture prior to overwintering. Since wine grapes have a high level of sugar content (20–25%) in the weeks prior to harvest (Plocher and Parke 2001), vineyards are an excellent location to increase sugar reserves. The importance of sugars to overwintering survival was suggested by studies in which beetles fed sugar water had higher survival rates than those given water alone (T. Galvan, unpublished data).

The primary problem with *H. axyridis* on wine grapes is attributed to it acting as a contaminant. Adults tend to aggregate on clusters with damaged grapes. If *H. axyridis* are disturbed or crushed during harvest and processing of the grapes, they release a yellow fluid (reflex bleeding), which creates an unpleasant odor and taste in the resulting wine (Pickering et al. 2004; Galvan et al. 2007a). The reflex bleeding fluid is released from the tibio-femoral joints of adults (Al Abassi et al. 1998; Dixon 2000; Laurent et al. 2001). The fluid contains alkaloids used for defense and 3-alkyl-2-methoxypyrazines that could be used as an aggregation pheromone or in Müllerian mimicry due to their strong smell (Moore et al. 1990; Al Abassi et al. 1998; Dixon 2000; Cudjoe et al. 2005). One 3-alkyl-2-methoxypyrazine, the 2-isopropyl-3-methoxypyrazine (IPMP), has been suggested to be one of the key compounds responsible for the taint produced by *H. axyridis* in wines (Pickering et al. 2005). In addition to IPMP, two other 3-alkyl-2-methoxypyrazines, the 2-sec-butyl-3-methoxypyrazine (SBMP) and 2-isobutyl-3-methoxypyrazine (IBMP) could also be affecting the 2-sec-butyl-3 wine flavor since they are found in *H. axyridis* (Cudjoe et al. 2005; Cai et al. 2007). These compounds are also well known for their contribution to vegetative, herbaceous, green bell pepper and earthy character of wines such as Cabernet Sauvignon and Sauvignon blanc (Allen et al. 1994; Sala et al. 2002).

### Integrated pest management in vineyards

An integrated pest management program for *H. axyridis* on wine grapes should be based on the timing of pest infestation (phenology), use of procedures to estimate levels of pest infestation (sampling methods), knowledge of the relationship between levels of infestation and resulting taint (sensory thresholds), and control methods. For phenology, *H. axyridis* adults begin to move to grape clusters between 2 and 3 weeks prior to harvest (Galvan et al. 2006b). This is the key management window. Even though *H. axyridis* populations increase or decrease throughout the growing season, grape growers should not worry about this pest until 2 or 3 weeks before harvest when the proportion of injured berries starts to increase, which then provides an opportunity for *H. axyridis* feeding on the grapes (Galvan et al. 2006b). *Harmonia axyridis* is found in vineyards as early as June when they are feeding on aphids or other small soft-bodied insects. Grape growers can follow *H. axyridis* population fluctuation in vineyards using yellow sticky traps, which can be used as an early warning tool as well.

Enumerative (e.g., number of beetles per cluster) and binomial (e.g., proportion of clusters infested) sampling plans were developed for *H. axyridis* in wine grapes (Galvan et al. 2007a). For enumerative plans, the average sample size (with a sample unit of one cluster) required to reach desired precision levels ranged from 180 to 546 clusters. By contrast, binomial plans resulted in a much lower required sample size of about 25 clusters depending on the threshold used (Galvan et al. 2007a). Because of this increased

efficiency, binomial sampling should be used for practical pest management purposes regarding this pest.

Sensory-based action thresholds were developed for *H. axyridis* in Frontenac wine grapes using a tasting panel and wine from artificially infested grapes (Galvan et al. 2007b). The estimated sensory threshold at which 10% of the population of wine consumers was able to detect the characteristic taint of *H. axyridis* is 1.9 beetles per kg of grapes, or 0.27 beetles per grape cluster of Frontenac (Galvan et al. 2007b). This sensory threshold is similar to the 0.2 *H. axyridis* adults per cluster suggested by Pickering et al. (2006a) for the white grape variety Riesling. Sensory thresholds can be interpreted as action thresholds for *H. axyridis* in wine grapes (i.e., number of *H. axyridis* per kg of grapes), which when combined with existing control methods and sampling plans, form the basis of integrated pest management for this insect in wine grapes.

Although remediation of tainted wine by adding oak chips, activated charcoal, and deodorized oak has decreased *H. axyridis*-related taint or IPMP concentration, it has not completely removed the taint from contaminated wine (Pickering et al. 2006b). Therefore, the use of control measures such as insecticides to manage *H. axyridis* before it can become a wine contaminant is essential for reducing the economic impact of this pest on the wine industry. In field and laboratory studies, carbaryl, bifenthrin, zeta-cypermethrin, thiamethoxam, and imidacloprid showed either toxic and/or repellent effects on *H. axyridis* (Galvan et al. 2006a). However, of these insecticides, only carbaryl, thiamethoxam and imidacloprid are currently labeled in the USA for use on wine grapes within 7 days of harvest, which is the period in which *H. axyridis* typically reaches high densities (Galvan et al. 2006b).

We are unaware of reports of *H. axyridis* feeding on fruits in its native Asian range. Therefore, the pest status that *H. axyridis* has attained in fruit production, particularly wine grapes, is clearly an unanticipated adverse consequence of the establishment of this beetle in North America. Even though other coccinellids have been documented feeding on fruits, none have attained pest status in fruit production. This unique pest situation deserves attention to improve our understanding of the biology and to further develop integrated pest management programs for this system. In addition, the impact of *H. axyridis* on other fruits such as raspberries deserves further attention.

## Conclusions

Despite the benefits offered as a biological control agent, *H. axyridis* is becoming known as a case of biological control gone awry. In North America, *H. axyridis* is having impacts on non-target arthropods, impacts on fruit production and impacts as a household invader. Because of these, Babendreier (2007) used the phrase “*Harmonia* cases” to refer to situations when the release of biological control agents results in adverse effects. Further work is needed to ensure the safety of future releases of biological control agents. For the case of *H. axyridis* in North America, the impacts on non-target arthropods and, to lesser extent, the impacts as a household invader possibly could have been anticipated, due to its generalist feeding preferences and overwintering behavior in Asia, respectively. However, it is unlikely that the impacts on fruit production could have been anticipated. Therefore, even in retrospect, it is difficult to predict the potential impacts that an introduced natural enemy might have in its adventive range.



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