

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

Robert L. Koch · Tederson L. Galvan

Received: 9 August 2007 / Accepted: 27 September 2007
© International Organization for Biological Control (IOBC) 2007

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:

R. L. Koch (✉)
Plant Protection Division, Minnesota Department of Agriculture, 625 Robert Street North, Saint Paul,
MN 55155, USA
e-mail: robert.koch@state.mn.us

T. L. Galvan
Department of Entomology, University of Minnesota, 1980 Folwell Avenue, Saint Paul, MN 55108,
USA

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., Krafsur 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 chrysomelid, *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, (-)- β -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 Čerkasov 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.

Acknowledgments We thank Helen Roy (CEH Monks Wood) for inviting us to contribute a paper to this special issue. We are grateful to Éric Lucas (Université du Québec à Montréal) for providing information about his recent research, and Geir Friisoe (Minnesota Department of Agriculture), Sandra Nogueira Koch (University of Minnesota) and three anonymous reviewers for providing reviews of this paper.

References

- Al Abassi S, Birkett MA, Petterson J, Pickett JA, Woodcock CM (1998) Ladybird beetle odour identified and found to be responsible for attraction between adults. *Cell Mol Life Sci* 54:876–879
- Allen MS, Lacey MJ, Boyd S (1994) Determination of methoxypyrazines in red wine by stable isotope dilution gas chromatography–mass spectrometry. *J Agric Food Chem* 42:1734–1738
- de Almeida LM, da Silva VB (2002) First record of *Harmonia axyridis* (Pallas) (Coleoptera, Coccinellidae): a lady beetle native to the Palaearctic region. *Rev Bras Zool* 19:941–944
- Alyokhin A, Sewell G (2004) Changes in a lady beetle community following the establishment of three alien species. *Biol Invasions* 6:463–471
- Babendreier D (2007) Pros and cons of biological control. In: Nentig W (ed) *Biological invasions*. Springer-Verlag, Berlin, pp 403–418
- Boettner GH, Elkinton JS, Boettner CJ (2000) Effects of a biological control introduction on three nontarget native species of saturniid moths. *Conserv Biol* 14:1798–1806
- Brown MW (2003) Intraguild responses of aphid predators on apple to the invasion of an exotic species, *Harmonia axyridis*. *BioControl* 48:141–153
- Brown MW, Miller SS (1998) Coccinellidae (Coleoptera) in apple orchards of eastern West Virginia and the impact of invasion by *Harmonia axyridis*. *Entomol News* 109:136–142
- Brown AE, Riddick EW, Aldrich JR, Holmes WE (2006) Identification of (-)- β -caryophyllene as a gender-specific terpene produced by the multicolored Asian lady beetle. *J Chem Ecol* 32:2489–2499
- Brown PMJ, Adriaens JS, Bathon H, Cuppen J, Goldarazena A, Hägg T, Kenis M, Klausnitzer BEM, Kovar I, Loomans AJM, Majerus MEN, Nedved O, Pederson J, Rabitsch W, Roy HE, Ternois V, Zakharov IA, Roy DB (2007) *Harmonia axyridis* in Europe: spread and distribution of a non-native coccinellid. *BioControl* (this issue). doi:10.1007/s10526-007-9132-y
- Cai L, Koziel JA, Matthew EO (2007) Determination of characteristic odorants from *Harmonia axyridis* beetles using in vivo solid-phase and multidimensional gas chromatography–mass spectrometry–olfactometry. *J Chromatogr A* 1147:66–78
- Chapin JB, Brou VA (1991) *Harmonia axyridis* (Pallas), the third species of the genus to be found in the United States (Coleoptera: Coccinellidae). *Proc Entomol Soc Wash* 93:630–635
- Coderre D, Lucas É, Gagné I (1995) The occurrence of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) in Canada. *Can Entomol* 127:609–611
- Colunga-Garcia M, Gage SH (1998) Arrival, establishment, and habitat use of the multicolored Asian lady beetle (Coleoptera: Coccinellidae) in a Michigan landscape. *Environ Entomol* 27:1574–1580
- Costamagna A, Landis DA (2006) Predators exert top-down control of soybean aphid across a gradient of agricultural management systems. *Ecol Appl* 16:1619–1628
- Cottrell TE (2004) Suitability of exotic and native ladybeetle eggs (Coleoptera: Coccinellidae) for development of lady beetle larvae. *Biol Control* 31:362–371
- Cottrell TE (2005) Predation and cannibalism of lady beetle eggs by adult lady beetles. *Biol Control* 34:159–164
- Cottrell TE, Yeangan KV (1998) Intraguild predation between an introduced lady beetle, *Harmonia axyridis* (Coleoptera: Coccinellidae), and a native lady beetle, *Coleomegilla maculata* (Coleoptera: Coccinellidae). *J Kans Entomol Soc* 71:159–163
- Cudjoe E, Wiederkehr TB, Brindle ID (2005) Headspace gas chromatography–mass spectrometry: a fast approach to the identification and determination of 2-alkyl-3-methoxypyrazine pheromones in ladybugs. *Analyst* 130:152–155
- Davis RS, Vandewalker ML, Hutcheson PS, Slavin RG (2006) Facial angioedema in children due to ladybug (*Harmonia axyridis*) contact: 2 case reports. *Ann Allergy Asthma Immunol* 97:440–442
- Day WH, Tatman KM (2006) Changes in abundance of native and adventive Coccinellidae (Coleoptera) in alfalfa fields, in northern New Jersey (1993–2004) and Delaware (1999–2004), U.S.A *Entomol News* 117:491–502
- Day WH, Prokrym DR, Ellis DR, Chianese RJ (1994) The known distribution of the predator *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae) in the United States, and thoughts on the origin of this species and five other exotic lady beetles in eastern North America. *Entomol News* 105:224–256

- de Wilde J (1970) Hormones and insect diapause. *Mem Soc Endocrinol* 18:487–514
- Dixon AFG (2000) Insect predator-prey dynamics: ladybird beetles and biological control. Cambridge University Press, Cambridge, 257 pp
- Dreistadt SH, Hagen KS, Bezark LG (1995) *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), first western United States record for this Asiatic lady beetle. *Pan-Pac Entomol* 71:135–136
- Flowers RW, Salom SM, Kok LT (2005) Competitive interactions among two specialist predators and a generalist predator of hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae), in the laboratory. *Environ Entomol* 34:664–675
- Fortune B (2000) They're everywhere! They're everywhere! *Lexington Herald*. 27 October 2000
- Fox TB, Landis DA, Cardoso FF, Difonzo CD (2004) Predators suppress *Aphis glycines* Matsumura population growth in soybean. *Environ Entomol* 33:608–618
- Fox TB, Landis DA, Cardoso FF, Difonzo CD (2005) Impact of predation on establishment of the soybean aphid, *Aphis glycines* in soybean, *Glycine max*. *BioControl* 50:545–563
- Galvan TL, Burkness EC, Hutchison WD (2006a) Efficacy of selected insecticides for management of the multicolored Asian lady beetle on wine grapes near harvest. *Plant Health Prog*. doi:10.1094/PHP-2006-1003-01-RS
- Galvan TL, Burkness EC, Hutchison WD (2006b) Influence of berry injury on infestations of the multicolored Asian lady beetle in wine grapes. *Plant Health Prog*. doi:10.1094/PHP-2006-0607-01-BR
- Galvan TL, Burkness EC, Hutchison WD (2006c) Wine grapes in the Midwest: reducing the risk of the multicolored Asian lady beetle. Public. 08232. University of Minnesota Extension Service, Saint Paul, MN, USA
- Galvan TL, Burkness EC, Hutchison WD (2007a) Enumerative and binomial sequential sampling plans for the multicolored Asian lady beetle (Coleoptera: Coccinellidae) in wine grapes. *J Econ Entomol* 100:1000–1010
- Galvan TL, Burkness EC, Vickers Z, Stenberg P, Mansfield AK, Hutchison WD (2007b) Sensory-based action threshold for the multicolored Asian lady beetle-related taint in wine grapes. *Am J Enol Vitic* (in press)
- Gardiner MM, Landis DA (2007) Impact of intraguild predation by adult *Harmonia axyridis* (Coleoptera: Coccinellidae) on *Aphis glycines* (Hemiptera: Aphididae) biological control in cage studies. *Biol Control* 40:386–395
- Gerhardt G (2000) Hordes of maddening ladybugs headed this way. *Rocky Mountain News*. 30 November 2000
- Goetz DW (2007) *Harmonia axyridis* ladybug hypersensitivity in clinical allergy practice. *Allergy Asthma Proc* 28:50–57
- Gordon RD (1985) The Coccinellidae (Coleoptera) of America north of Mexico. *J New York Entomol Soc* 93:1–912
- Hagen KS (1962) Biology and ecology of predaceous Coccinellidae. *Ann Rev Entomol* 7:289–3226
- Harmon JP, Ives AR, Losey JE, Olson AC, Rauwald KS (2000) *Coleomegilla maculata* (Coleoptera: Coccinellidae) predation on pea aphids promoted by proximity to dandelions. *Oecologia* 125:543–548
- Harmon JP, Stephens E, Losey J (2007) The decline of native ladybirds (Coleoptera: Coccinellidae) in the United States and Canada. *J Insect Conserv* 11:85–94
- Hemptinne JL, Desprets A (1986) Pollen as a spring food for *Adalia bipunctata*. In: Hodek I (ed) *Ecology of Aphidophaga*. Dr W Junk, Dordrecht, pp 29–35
- Hesler LS, Kieckhefer RK, Catangui MA (2004) Surveys and field observation of *Harmonia axyridis* and other Coccinellidae (Coleoptera) in eastern and central South Dakota. *Trans Am Entomol Soc* 130: 113–130
- Hodek I (1986) Life cycle strategies, diapause and migration in aphidophagous Coccinellidae. In: Hodek I (ed) *Ecology of Aphidophaga*. Dr. W. Junk, Dordrecht, pp 155–166
- Hodek I, Čerkašov J (1963) Imaginal dormancy in *Semiadalia undecimnotata* Schneid. (Coccinellidae, Col.) II. Changes in water, fat and glycogen content. *Acta Soc Zool Bohem* 27:298–318
- Hodek I, Honěk A (1996) *Ecology of Coccinellidae*. Kluwer Academic Publishers, Dordrecht, 464 pp
- Howarth FG (1991) Environmental impacts of classical biological control. *Ann Rev Entomol* 36:485–509
- Huelsman M, Kovach J (2004) Behavior and treatment of the multicolored Asian lady beetle (*Harmonia axyridis*) in the urban environment. *Am Entomol* 50:163–164
- Huelsman MF, Kovach J, Jasinski J, Young C, Easley B (2002) Multicolored Asian lady beetle (*Harmonia axyridis*) as a nuisance pest in households in Ohio. In: Jones SC, Zhai J, Robinson WH (eds) *Proceedings of 4th international conference on urban pests*, pp 243–250
- Kidd K, Nalepa CA, Day ER, Waldvogel MG (1995) Distribution of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) in North Carolina and Virginia. *Proc Entomol Soc Wash* 97:729–731

- Koch RL (2003) The multicolored Asian lady beetle, *Harmonia axyridis*: a review of its biology, uses in biological control and non-target impacts. *J Insect Sci* 3:1–16
- Koch RL, Hutchison WD, Venette RC, Heimpel GE (2003) Susceptibility of immature monarch butterfly, *Danaus plexippus* (Lepidoptera: Nymphalidae: Danainae), to predation by *Harmonia axyridis* (Coleoptera: Coccinellidae). *Biol Control* 28:265–270
- Koch RL, Burkness EC, Burkness SJ, Hutchison WD (2004) Phytophagous preferences of the multicolored Asian lady beetle (Coleoptera: Coccinellidae) to autumn ripening fruit. *J Econ Entomol* 97:539–544
- Koch RL, Burkness EC, Hutchison WD (2006a) Spatial distribution and fixed-precision sampling plans for the ladybird *Harmonia axyridis* in sweet corn. *BioControl* 51:741–751
- Koch RL, Venette RC, Hutchison WD (2006b) Predicted impact of an invasive generalist predator on monarch butterfly (Lepidoptera: Nymphalidae) populations: a quantitative risk assessment. *Biol Invasions* 8:1179–1193
- Koch RL, Venette RC, Hutchison WD (2006c) Invasions by *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) in the western hemisphere: implications for South America. *Neotrop Entomol* 35:421–434
- Koehler D (2002) Steroid Asian lady beetles move into town. *Grand Forks Herald*. 13 September 2002
- Kovach J (2004) Impact of multicolored Asian lady beetles as a pest of fruit and people. *Am Entomol* 50:159–161
- Krafsur ES, Kring TJ, Miller JC, Nariboli P, Obyrck JJ, Ruberson JR, Schaefer PW (1997) Gene flow in the exotic colonizing ladybeetle *Harmonia axyridis* in North America. *Biol Control* 8:207–214
- Kuznetsov VN (1997) Lady beetles of the Russian Far East. The Sandhill Crane Press, Inc., Gainesville, 248 pp
- Labrie G, Lucas É, Coderre D (2006) Can developmental and behavioral characteristics of the multicolored Asian lady beetle *Harmonia axyridis* explain its invasive success? *Biol Invasions* 8:743–754
- LaMana ML, Miller JC (1996) Field observations on *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae) in Oregon. *Biol Control* 6:232–237
- LaRock DR, Ellington JJ (1996) An integrated pest management approach, emphasizing biological control, for pecan aphids. *Southwest Entomol* 21:153–167
- Laurent P, Lebrun B, Braekman J, Daloze D, Pasteels JM (2001) Biosynthetic studies on adaline and adalinine, two alkaloids from ladybird beetles (Coleoptera: Coccinellidae). *Tetrahedron* 57:3403–3412
- Louda SM, Pemberton RW, Johnson MT, Follett PA (2003) Nontarget effects—the Achilles’ heel of biological control? Retrospective analysis to reduce risk associated with biocontrol introductions. *Ann Rev Entomol* 48:369–396
- Lucas É, Gagné I, Coderre D (2002) Impact of the arrival of *Harmonia axyridis* on adults of *Coccinella septempunctata* and *Coleomegilla maculata* (Coleoptera: Coccinellidae). *Eur J Entomol* 99:457–463
- Majerus MEN (1994) Ladybirds in winter. In: Majerus M (ed) Ladybirds. *New naturalist* 81. Harper Collins, London, 320 pp
- Majerus MEN (1997) How is *Adalia bipunctata* (Linn.) (Coleoptera: Coccinellidae) attracted to overwintering sites? *Entomologist* 116:212–217
- Majerus M, Kearns P (1989) Ladybirds. Richmond Publishing Co. Ltd., Slough, 103 pp
- McCorquodale DB (1998) Adventive lady beetles (Coleoptera: Coccinellidae) in eastern Nova Scotia, Canada. *Entomol News* 109:15–20
- Michaud JP (2002) Invasion of the Florida Citrus ecosystem by *Harmonia axyridis* (Coleoptera: Coccinellidae) and asymmetric competition with a native species, *Cycloneda sanguinea*. *Environ Entomol* 31:827–835
- Mignault M-P, Roy M, Brodeur J (2006) Soybean aphid predators in Quebec and the suitability of *Aphis glycines* as prey for three Coccinellidae. *BioControl* 51:89–106
- Moore BP, Brown WV, Rothschild M (1990) Methylalkylpyrazines in aposematic insects, their hostplants and mimics. *Chemoecology* 1:43–51
- Musser FR, Nyrop JP, Shelton AM (2004) Survey of predators and sampling method comparison in sweet corn. *J Econ Entomol* 97:136–144
- Nalepa CA, Kidd KA, Ahlstrom KR (1996) Biology of *Harmonia axyridis* (Coleoptera: Coccinellidae) in winter aggregations. *Ann Entomol Soc Am* 89:681–685
- Nalepa CA, Kidd KA, Hopkins DI (2000) The multicolored Asian ladybeetle (Coleoptera: Coccinellidae): orientation to aggregation sites. *J Entomol Sci* 35:150–157
- Nalepa CA, Kennedy GG, Brownie C (2004) Orientation of multicolored Asian lady beetles to buildings. *Am Entomol* 50:165–166
- Nalepa CA, Kennedy GG, Brownie C (2005) Role of visual contrast in the alighting behavior of *Harmonia axyridis* (Coleoptera: Coccinellidae) at overwintering sites. *Environ Entomol* 34:425–431

- Nault BA, Kennedy GG (2003) Establishment of multicolored Asian lady beetle in eastern North Carolina: seasonal abundance and crop exploitation within an agricultural landscape. *BioControl* 48:363–378
- Obata S (1986) Determination of hibernation site in the ladybird beetle, *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae). *Kontyu* 54:218–223
- Opara LU, Studman CJ, Banks NH (1997) Fruit skin splitting and cracking. *Hort Rev* 19:217–262
- Park YL, Obrycki JJ (2004) Spatio-temporal distribution of corn leaf aphids (Homoptera: Aphididae) and lady beetles (Coleoptera: Coccinellidae) in Iowa cornfields. *Biol Control* 31:210–217
- Pervez A, Omkar (2006) Ecology and biological control application of multicoloured Asian ladybird, *Harmonia axyridis*: a review. *Biocontrol Sci Technol* 16:111–128
- Phoofolo MW, Obrycki JJ (1998) Potential for intraguild predation and competition among predatory Coccinellidae and Chrysopidae. *Entomol Exp Appl* 89:47–55
- Pickering GJ, Lin J, Riesen R, Reynolds A, Brindle I, Soleas G (2004) Influence of *Harmonia axyridis* on the sensory properties of white and red wine. *Am J Enol Vitic* 55:153–159
- Pickering GJ, Lin J, Reynolds A, Soleas G, Riesen R, Brindle I (2005) The influence of *Harmonia axyridis* on wine composition and aging. *J Food Sci* 70:128–135
- Pickering GJ, Lin J, Ker K (2006a) Origin and remediation of Asian lady beetle (*Harmonia axyridis*) taint in wine. In: Dris R (ed) *Crops: growth, quality and biotechnology. III. Quality management of food crops for processing technology*. WFL Publisher, Helsinki, pp 785–794
- Pickering GJ, Lin J, Reynolds A, Soleas G, Riesen R (2006b) The evaluation of remedial treatments for the wine affected by *Harmonia axyridis*. *Inter J Food Sci Tech* 41:77–86
- Plocher TA, Parke RJ (2001) Northern winework: growing grapes and making wine in cold climates. Northern Winework, Inc., Hugo
- Ray JN, Pence HL (2004) Ladybug hypersensitivity: report of a case and review of the literature. *Allergy Asthma Proc* 25:133–136
- Ricci C, Ponti L (2002) Seasonal food of *Ceratomegilla notata* (Coleoptera: Coccinellidae) in mountain environments of Northern Italian Alps. *Eur J Entomol* 102:527–530
- Riddick EW, Aldrich JR, de Milo A, Davis JC (2000) Potential for modifying the behavior of the multicolored Asian lady beetle (Coleoptera: Coccinellidae) with plant-derived natural products. *Ann Entomol Soc Am* 93:1314–1321
- Riddick EW, Aldrich JR, Davis JC (2004) DEET repels *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) adults in laboratory bioassays. *J Entomol Sci* 39:373–386
- Rosenheim JA, Kaya HK, Ehler LE, Marois JJ, Jaffee BA (1995) Intraguild predation among biological control agents: theory and evidence. *Biol Control* 5:303–335
- Roy H, Rowland F, Brown P, Ware R, Majerus M (2005) Ecology of the harlequin ladybird—a new invasive species. *Brit Wildlife* 16:403–407
- Rutledge CE, O'Neil RJ, Fox TB, Landis DA (2004) Soybean aphid predators and their use in integrated pest management. *Ann Entomol Soc Am* 97:240–248
- Saini ED (2004) Presencia de *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) en la provincia de Buenos Aires. Aspectos biológicos y morfológicos. *RIA* 33:151–160
- Sakurai H, Kumada Y, Takeda S (1993) Seasonal prevalence and hibernating-diapause behavior in the lady beetle, *Harmonia axyridis*. *Res Bull Fac Agric Gifu Univ* 58:51–55
- Sala C, Mestres M, Martí MP, Busto O, Guasch J (2002) Headspace solid-phase microextraction analysis of 3-alkyl-2-methoxy-pyrazines in wines. *J Chromatogr A* 953:1–6
- Sato S, Yasuda H, Evans EW (2005) Dropping behaviour of larvae of aphidophagous ladybirds and its effects on incidence of intraguild predation: interactions between the intraguild prey, *Adalia bipunctata* (L.) and *Coccinella septempunctata* (L.), and the intraguild predator, *Harmonia axyridis* Pallas. *Ecol Entomol* 30:220–224
- Sebolt DC, Landis DA (2004) Arthropod predators of *Galerucella californiensis* L. (Coleoptera: Chrysomelidae): an assessment of biotic interference. *Environ Entomol* 33:356–361
- Shapiro-Ilan DI, Cottrell TE (2005) Susceptibility of lady beetles (Coleoptera: Coccinellidae) to entomopathogenic nematodes. *J Invert Path* 89:150–156
- Simberloff D, Stiling P (1996) How risky is biological control. *Ecology* 77:1965–1974
- Smith BC (1960) A technique for rearing Coccinellid beetles on dry foods, and influence of various pollens on the development of *Coleomegilla maculate lengi* Timb. (Coleoptera: Coccinellidae). *Can J Zool* 38:1047–1049
- Snyder WE, Clevenger GM, Eigenbrode SD (2004) Intraguild predation and successful invasion by introduced ladybird beetles. *Oecologia* 140:559–565
- Tedders WL, Schaefer PW (1994) Release and establishment of *Harmonia axyridis* (Coleoptera: Coccinellidae) in the southeastern United States. *Entomol News* 105:228–243

- Wallace MS, Hain FP (2000) Field surveys and evaluation of native and established predators of the hemlock woolly adelgid (Homoptera: Adelgidae) in the Southeastern United States. *Environ Entomol* 29:638–644
- Yarbrough JA, Armstrong JL, Blumberg MZ, Phillips AE, McGahee E, Dolen WK (1999) Allergic rhinoconjunctivitis caused by *Harmonia axyridis* (Asian lady beetle, Japanese lady beetle, or lady bug). *J Allergy Clin Immunol* 104:704–709
- Yasuda H, Evans EW, Kajita Y, Urakawa K, Takizawa T (2004) Asymmetrical larval interactions between introduced and indigenous ladybirds in North America. *Oecologia* 141:722–731
- Yasumatsu K, Watanabe C (1964) A tentative catalogue of insect natural enemies of injurious insects in Japan—part 1. Parasite–predator host catalogue. Entomological Laboratory, Faculty of Agriculture Kyushu University, Fukuoka