CHAPTER 15

HARMONIA AXYRIDIS: A SUCCESSFUL BIOCONTROL AGENT OR AN INVASIVE THREAT?

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1. Introduction

The harlequin ladybird, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) is an aphidophagous coccinellid, native to central and eastern Asian (Kuznetsov, 1997). This predatory ladybird has been available in many countries for use as a biological control agent of pest insects including aphids and scale insects. Since 1916 *H. axyridis* has been repeatedly released as a classical biological control agent in the USA (Gordon, 1985). It established in the 1980s and has spread and increased in number dramatically so that it is now the dominant species of ladybird in many parts of North America (Hesler *et al.,* 2001; Smith *et al.,* 1996; Tedders and Schaefer, 1994). In mainland Europe it has been commercially available for both classical and inundative biological control strategies since 1982 (Iperti and Bertand, 2001) and has become established in France, Belgium, Holland, Germany, Luxemburg and Italy. It has also been released in South America and the Middle East. *Harmonia axyridis* has not been intentionally released in the UK, however given the proximity of the SE of Britain to the French, Belgium and Dutch coasts it was inevitable that it would arrive. In mid September 2004 a male was found in Essex (SE England).

The arrival of *H. axyridis* in the UK has been met with considerable concern both from ecological and anthropogenic perspectives. In this chapter we address both the perceived potential problems and the possible benefits associated with the arrival of this invasive species. In addition we report on methods of monitoring *H. axyridis* in the UK and the initial public response to a national survey involving this alien species and the native coccinellids with which it may interact.

2. Biology of *Harmonia axyridis*

2.1. Dietary range

Harmonia axyridis is a polyphagous species. It has a wider dietary range of essential prey than most other predatory coccinellids. It most often feeds on aphids, but will also consume coccids, psyllids and adelgids as essential prey. It can breed and develop on the immature stages of other coccinellids and, in captivity, the eggs of the flour moth *Ephestia kuhniella* are used as essential food. Alternative foods (*sensu* Hodek, 1996) include many other invertebrate prey, nectar, pollen, honeydew, plant sap and the juice of ripe fruit.

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2.2. Colour variation

The colour pattern of the pronota and elytra of *H. axyridis* are highly variable. The ground colour may be orange, red or black. The orange and red forms may be patterned with zero to 21 black spots (f. *succinea* complex) or may have a grid-like black pattern (f. *axyridis*). The black (melanic) forms commonly have two (f. *conspicua*) or four (f. *spectabilis*) orange or red spots. Many other forms with bars, stripes or splodges have been reported from its native range (e.g. Dobzhansky, 1933). The differences between forms are largely controlled by alleles of major genes (Hosina, 1933, 1936; Tan and Li, 1934; Komai, 1956), but environmental factors, such as temperature and diet also have some effect (Majerus and Roy, in press a). The phenotypic variability of *H. axyridis* facilitates the adaptability of this species in terms of life-history traits, competitive ability and habitat diversity (Grill *et al*., 1997).

2.3. Habitat range

Harmonia axyridis is widely reported as a semiarboreal species (Hodek, 1973; LaMana and Miller, 1996); however it also thrives and breeds in agricultural habitats (LaMana and Miller, 1996). The eurytopic nature of *H. axyridis* is further supported by the broad range of habitats, including coniferous woodland and reed-beds, in which it survives and reproduces in its extensive native Asian range. Native UK ladybirds tend to be more habitat and niche-specific than *H. axyridis* (Majerus, 1994).

2.4. Climatic range

The wide latitudinal and longitudinal range of *Harmonia axyridis* demonstrates the adaptability of this species to diverse climatic regimes.*H. axyridis* can survive winter temperatures below freezing and summer temperatures of 30°C (LaMana and Miller, 1998). These temperatures are within the range which is currently experienced across the UK. Furthermore, the effects of climate change are already evident across the UK and predictions suggest the trend of global warming will continue. The climatic adaptability of *H. axyridis* will provide it with a competitive advantage over less adaptable UK native coccinellids. Whereas some native species of ladybird (such as *Coccinella septempunctata*) require a period of dormancy prior to commencing reproduction, *H. axyridis* can breed continuously. Therefore, global warming would allow this species the possibility of reproducing over a longer time period. The polyphagous nature of *H. axyridis* would facilitate the survival of larvae regardless of the food type available at different times of the year. Indeed, in early November 2004, after native UK ladybirds had dispersed to overwintering sites, *H. axyridis* larvae and pupae were still active. Moreover, sightings of active *H. axyridis* in England in March and April 2005 demonstrate that it is capable of surviving the British winter climate.

2.5. Dispersal ability

In both Asia and America *H. axyridis* undertakes long migratory flights to and from overwintering sites (LaMana and Miller, 1996). Furthermore, this species is also highly dispersive during the breeding period as it searches for host plants with high densities of aphids. This high dispersal ability has certainly contributed to the rapid colonization of North America by *H. axyridis* and we predict that by 2008 *H. axyridis* will have spread across mainland Britain. Indeed the arrival of *H. axyridis* is in part attributed to its ability to disperse from

mainland Europe across the English Channel to the UK; although it is also known that some individuals have arrived on fruit and cut flowers (Majerus *et al*., in press).

3. *Harmonia axyridis*: A successful biological control agent?

Predatory ladybirds are widely considered as important biological control agents and there are examples of their use in all four biological control strategies: classical biological control, inoculation biological control, inundation biological control and conservation biological control. Indeed the Australian vedalia ladybird, *Rodolia cardinalis*, marked the advent of modern biological control. In 1888 the vedalia ladybird was released to control cottony cushion scale insects, *Icerya purchasi*, which were devastating the citrus industry of California. The introduction and subsequent establishment of this ladybird resulted in a dramatic decrease in scale insects (Majerus, 1994).

There have been many other examples of successful control of scale insects by various ladybird species (De Bach, 1964; Dixon, 2000). However, the control of aphids by ladybirds has largely been unsuccessful (Dixon, 2000). This has been attributed to the asynchrony of ladybirds with early season outbreaks of aphids and also the slow reproductive rate of ladybirds in comparison to aphids (Coderre, 1988; Majerus, 1994; Dixon, 2000). Furthermore, the release of generalist predators for biological control programmes is contentious for a number of reasons:

1. Inconsistent and long delays in post-release recovery (LaMana and Miller, 1996)
2. Potential to outcompete and displace other guild members (Rosenheim et al, 1994)
3. Impacts on non-target species (Howarth, 1991)

Harmonia axyridis has been used as a biological control agent around the world. Since 1982, *H. axyridis* has been commercially available in Europe and has had a much longer history in North America. It was first released in California in 1916 as a classical biological control agent but failed to establish. Numerous subsequent releases in various parts of North America also failed. However, in 1988 populations were found in Louisiana (Chapin and Brou, 1991). Whether these populations resulted from intentionally released beetles, or accidental migrants is still a matter of debate (Day *et al*., 1994; Tedders and Schaefer, 1994). Since the late 1980's *H. axyridis* has colonised much of the USA and latterly Canada. It is rapidly becoming the dominant species of ladybird in North America.

Harmonia axyridis has many attributes that contribute to its biological control potential but perhaps the most important is that it preys on a wide variety of homopteran insects such as aphids, psyllids, coccids and adelgids (Hodek, 1996; Koch, 2003). Both as an introduced biocontrol agent in North America and in its native Asia, *H. axyridis* has been reported to contribute to control of aphids on sweet corn (Musser and Shelton, 2003), alfalfa (Buntin and Bouton, 1997; Colunga-Garcia and Gage, 1998), cotton (Wells *et al*., 2001), tobacco (Wells and McPherson, 1999), winter wheat (Colunga-Garcia and Gage, 1998), soybean (Koch, 2003), pecans (Tedders and Schaefers, 1994; LaRock and Ellington, 1996) and apples (Brown and Miller, 1998). In China *H. axyridis* has also been used as an augmentative biocontrol agent for the control of coccids in pine forests (Wang, 1986). Therefore, the increase of *H. axyridis* throughout the UK may prove to be beneficial in reducing aphid numbers below economically damaging levels within many crop systems and so reducing the use of chemical pesticides.

Due to its wide dietary range, *H. axyridis* may also provide control of some other pest species, such as adelgids in conifer plantations and coccids generally. Furthermore, its impact may not be restricted to essential prey species. As *H. axyridis* feeds on many insects as alternative prey, when essential prey are not available, it may reduce populations of other herbivorous pests, as Yakhontov (1960) showed when *Brumus 8-signatus* and *Semiadalia 11-notata* were used to control the weevil *Phytonomus posticus* on lucerne.

Harmonia axyridis is compatible with many integrated pest management strategies. Koch (2003) reviewed the impact of pesticides on *H. axyridis* and although broad spectrum insecticides were found to be lethal to *H. axyridis*, synthetic pyrethroids and new pesticides, such as spinosad, indoxacarb and pyriproxyfen, were considerably less toxic to *H. axyridis* than to aphids. Fungicides also have little toxic effect on *H. axyridis* (Michaud and Grant 2003; Wells et al, 2001). Studies assessing the impact of insect resistant transgenic crops on *H. axyridis* have shown negative effects to be negligible (Musser and Shelton 2003; Wold et al, 2001; Ferry et al, 2003).

It can, therefore, be concluded that *H. axyridis* can be used as a compatible and effective component of integrated pest management schemes (Koch, 2003). However, the very traits that contribute to the success of *H. axyridis* as a biological control agent (size, diverse dietary range, predatory efficiency and wide niche colonisation ability) are of concern when the wider ecological impacts of this species are considered.

4. Problems associated with *Harmonia axyridis*

4.1. Ecological implications

The generalist diet of *H. axyridis* means that negative impacts on non-target prey species would appear to be inevitable and the native guild of predators, parasitoids and parasites that surround these prey will also be adversely affected. However, studies on this are sparse. Koch *et al.* (2003) have already identified *H. axyridis* as a potential predator of immature monarch butterflies, *Danaus plexippus*, even though these butterflies contain defensive chemicals. It is likely that many other species will be directly or indirectly affected by the arrival of *H. axyridis*.

There is evidence to suggest that *H. axyridis* is adversely affecting other aphidophages. Sato *et al.* (2005) reported that, in a laboratory study assessing the interactions between different species of ladybird larvae, 95% of *Adalia bipunctata* and 55% of *C. septempunctata* were consumed by *H. axyridis*. This supports field studies that identified declines in populations of *Brachiacantha ursine*, *Cycloneda munda* and *Chilocorus stigma* in Michigan and abundance of native coccinellids in apple orchards in West Virginia following the establishment of both *C. septempunctata* and *H. axyridis* (Brown and Miller, 1998; Colunga-Garcia and Gage, 1998). There are three ways in which *H. axyridis* is likely to negatively affect other aphidophages: resource competition, intraguild predation and inter-specific competition.

Harmonia axyridis is highly voracious (consuming up to 65 aphids per day), fertile and fecund and so has the potential to directly out-compete other aphidophages (Michaud, 2000). Furthermore, *H. axyridis* has a wider dietary range than many other aphidophagous coccinellids. This, coupled with its ability to disperse rapidly, forage widely and breed continuously, gives *H. axyridis* a considerable advantage over British aphidophages in competition for prey species.

It is clear that *H. axyridis* is one of the top predators within aphidophagous and coccidophagous guilds and can thrive on a varied diet, including other species of ladybird (Yasuda and Ohnuma, 1999; Sato *et al*., 2005) and parasitized aphids (Nakata, 1995). Furthermore, in Japan *H. axyridis* arrives in alfalfa fields just after a number of other ladybirds allowing *H. axyridis* to feed on the prepupae and pupae of other coccinellids (Takahashi, 1989). It has been shown that *H. axyridis* will prey on immature stages of three of the most common aphidophagous coccinellids in Britain, *C. septempunctata* (Yasuda *et al*., 2001), *A. bipunctata* (Burgio *et al*., 2002) and *Propylea quatuordecimpunctata* (Lynch *et al*., 2001). In contrast, evidence suggests that the immature stages of *H. axyridis* are rarely eaten by other aphidophagous insects. It appears that the defensive chemistry of *H. axyridis* ensures that larval stages of other coccinellid species find it unpalatable (Agarwala and Dixon, 1992). Impact studies into the effect of *H. axyridis* on other aphidophages, such as Neuroptera, the larvae of some syrphids and parasitoids of aphids are lacking and urgently needed. However, it is likely that all of these groups will suffer through inter-specific competition, and some may also be negatively affected by intraguild predation.

A recent methodology for risk assessment (developed within the EU-financed project "Evaluating Environmental Risks of Biological Control into Europe (ERBIC)") has been developed for the regulation and release of exotic natural enemies (Van Lenteren *et al*., 2003). This general framework integrates information on the potential of a prospective biological control agent to establish, its dispersal ability, host range and direct and indirect impacts on non-targets. It is notable that *H. axyridis* was allocated a high-risk index when this proposed methodology was applied to it as a biological control agent. Host range is regarded as a critical element in the risk evaluation process and it is stated that "*lack of host specificity might lead to unacceptable risk if the agent establishes and disperses widely whereas, in contrast, a monophagous biological control agent is not expected to create serious risk even when it establishes and disperses well*" (Van Lenteren *et al*., 2003).

Adequate risk assessment and regulation of potential biological control agents are essential if the continued good reputation of biological control is to be maintained. The use of high risk, exotic species should be implemented with extreme caution. It has been recognised that for some species there may be a high probability of adverse ecological effects but these may not be realised under the specific conditions of release, for example in greenhouses (Van Lenteren *et al.,*2003). Biological control theory dictates that host specific agents are the most acceptable, both from efficacy and safety perspectives, however economics ensures that voracious species with wide host ranges are attractive to commercial producers. However, in the case of highly polyphagous, dispersive and adaptable species, such as *H. axyridis*, potential risks of use, even in restricted circumstances, may be greater than potential benefits.

In summary, *H. axyridis* is undoubtedly a dominant unidirectional intraguild predator and, although levels of intraguild predation are inversely correlated to aphid or coccid density (Hironori and Katsuhiro, 1997; Burgio *et al*.,2002), it has the potential to dramatically disrupt native aphidophagous and coccidophagous guilds in Britain.

4.2. Anthropogenic implications

In North America *H. axyridis* has become a nuisance to humans and is now, ironically, widely considered to be a pest. This is mainly a consequence of its behaviour when conditions become unfavourable both in late summer, when aphid populations decline, and in autumn, as adverse climatic conditions stimulate *H. axyridis* to undertake long-range migrations from their feeding

habitats to overwintering sites (Huelsman *et al*.,2002). Both scenarios lead adult *H. axyridis* to aggregate in large numbers.

In late summer it is essential that *H. axyridis* adults build up their energy reserves to ensure overwintering survival. At this time aphids are often scarce and so *H. axyridis* switch to feeding on the sweet sap of ripe fruits, such as apples and pears, blemishing the fruits and reducing the value of the crop. This has gained *H. axyridis* the status of a potential fruit production and processing pest in North America. This ladybird is also problematic in vineyards because *H. axyridis* feeds on the ripe grapes. The beetles are difficult to separate from the grapes at harvest and so they are crushed with the crop and their bitter-tasting, alkaloid defensive chemicals can seriously taint the vintage (Ratcliffe, 2002).

As adverse winter conditions approach, *H. axyridis* adults aggregate in large numbers in suitable overwintering sites such as houses, sheds and garages (Kidd *et al*.,1995). As the temperature increases, either through central heating or the onset of spring, the ladybirds increase in activity and begin to crawl and fly inside homes (Huelsman *et al*., 2002). Reflex blood is exuded from the femoro-tibial joints if the ladybirds are aggravated and this has a foul odour and stains soft furnishings. Once *H. axyridis* becomes active, it seeks food, and will then bite people to assess whether they are palatable. The resultant bites feel like a sting as a result of the predigestive enzymes injected into the incision, and a small bump usually develops. A few people have shown a hyperallergic reaction to *H. axyridis*, in the form of allergic rhinoconjunctivitis (Huelsman *et al*.,2002; Yarbrough *et al*., 1999).

5. The Harlequin Ladybird survey

The arrival of *H. axyridis* in the UK stimulated researchers from Cambridge University, the Centre for Ecology and Hydrology and Anglia Polytechnic University to initiate the Harlequin Ladybird Survey. We recognized that *H. axyridis* should be monitored for a number of reasons. First, it is critical to assess whether the potential ecological and anthropogenic impacts will be realized in the UK, using North America as a case study. Second, the discovery of *H. axyridis* in Britain provides a unique opportunity to study an invasive species from the time of arrival and so provides a model system for monitoring invasive species. Furthermore, the arrival presents the rare opportunity to address a range of evolutionary questions as a Founder population adapts phenotypically and genotypically to equilibrium states under selection. In *H. axyridis*, studies on changes in frequencies of colour-pattern morphs and changes in the prevalence of male-killing bacteria following arrival provide unique opportunities to investigate the evolution and maintenance of melanic polymorphism and sex ratio distorters respectively (Majerus and Roy, in press b).

5.1. What is the Harlequin Ladybird Survey?

The Harlequin Ladybird Survey and the UK Ladybird Survey are collaborative projects designed to monitor both the spread of *H. axyridis* across the UK and to assess the status of native ladybird populations. These projects are funded by the Department of Food and Rural Affairs (Defra) through the National Biodiversity Network Trust (NBNT). The further support that this research has received from many organizations including: Centre for Environmental Data and Recording (CEDaR), Joint Nature Conservancy Council (JNCC), Field Studies

Council (FSC), the Royal Society for the Protection of Birds (RSPB), Natural History Museum (London), British Wildlife Trusts and the National Trust is testament to the perceived importance of this study.

The surveys were launched on the 15th March 2005 with the support of two websites: the first for specific monitoring of the *H. axyridis* (www.harlequin-survey.org) and the second for recording native ladybird species (www.ladybird-survey.org). Both websites have been designed to engage the public to contribute to the survey and so provide general information on ladybirds and enable recording either on-line or using conventional post (Figure 1).

Ladybird records are highlighted as verified or unverified within the database. A verified record is one in which the specimen or a photo of the specimen has been seen and identified by one of the contributing scientists. Recorders are strongly encouraged to seek verification of their record and many have done so. This data enables distribution maps to be plotted and these are updated frequently on the website.

In addition to these general surveys other approaches have been developed to target specific groups including: young people (through the RSPB Wildsquare initiative), wildlife enthusiasts (through talks at wildlife societies) and experienced entomologists (through journals such as *Antenna*, *Entomologist's Monthly Magazine* and *The Bulletin of the Amateur Entomologists' Society*). The latter two groups are encouraged to establish transects (approximately 1-2 Km) to be monitored repeatedly through the active season for ladybirds and to replicate in following years, so that the impact of the arrival of *H. axyridis* on native coccinellids can be assessed.

5.2. Media attention

As outlined, engaging the public to help record *H. axyridis* and other ladybirds is a significant part of the project and the public response has been enormous. This has been aided by the publicity that the project has received through the national press. Just after the first report of *H. axyridis* was confirmed, on 4th October 2004 a press release was issued from Cambridge University, it began:

"The Ladybird Has Landed

A new ladybird has arrived in Britain. But not just any ladybird: this is *Harmonia axyridis*, the most invasive ladybird on Earth."

From this the press coverage that *H. axyridis* received was vast. Most of the national papers and many of the national and regional radio and television stations produced pieces highlighting the arrival of *H. axyridis* and the threat it posed both ecologically and anthropogenically. Very few highlighted the benefits of this species as a successful biological control agent. Following this initial publicity there were 110 confirmed reports of *H. axyridis* mostly in SE England (Figure 2).

On the 15th March 2005 another press release was issued to announce the launch of the websites for the surveys. This one began:

"Hunt for the harlequin – A UK survey for the world's most invasive ladybird

Britain's best loved beetle, the ladybird, is under threat from the world's most invasive species – the harlequin ladybird (*Harmonia axyridis*)."

The Harlequin Ladybird Survey

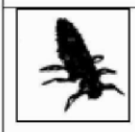
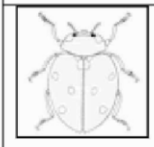
Harlequin Ladybird Recording Form

Name: **Date**:

Address:

Postcode:

Email address: (*Please include this if you have one!*)

What you found (circle)		**How many?** (circle)
	Larvae	1 / 1-5 / 6-10 / more than 10
	Adults	1 / 1-5 / 6-10 / more than 10

Where you found this:
(*Please include a grid reference, a postcode and/or name of the site*)

What was it doing?
(*E.g. flying, walking on the ground, sitting on a leaf, eating a greenfly…)*

Please send us photos or live specimens if you are able

http://www.harlequin-survey.org/

Figure 1: Harlequin ladybird recording form used for either on-line recording or postal submissions

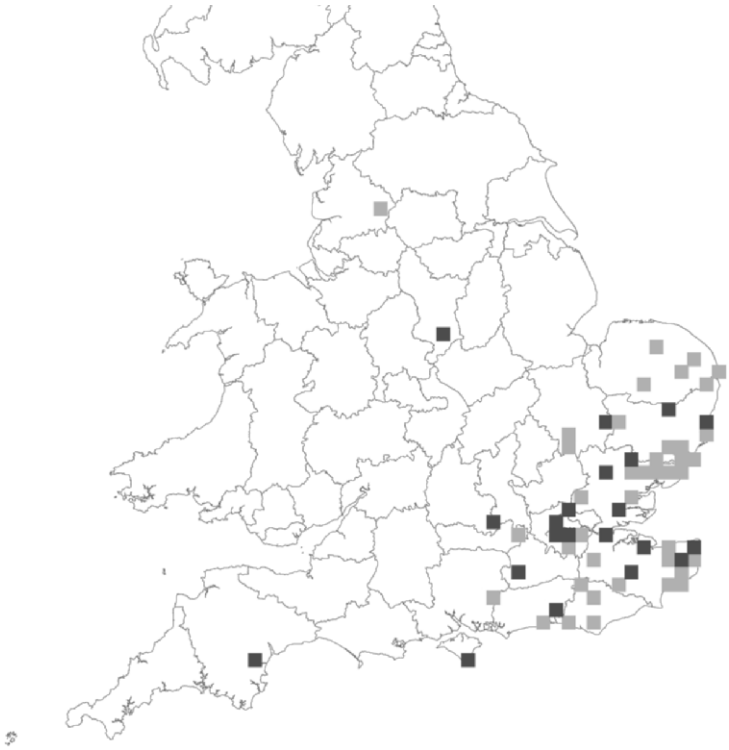


Figure 2: Distribution of Harmonia axyridis *in the UK (records up to 19th April 2005). Orange squares = 2004; Red squares = 2005*

The press coverage of this launch was even greater than the initial response in October 2004 and made front page news in *The Times*. Again the emphasis was on the negative impacts of *H. axyridis*, and in particular its threat to native ladybirds, which was emphasized as having implications to both the biodiversity and biological control potential of native species. The publicity gained from this launch was highly beneficial in advertising the websites. Within a few hours the Harlequin Survey website had received over 4000 visits. Over the first five weeks immediately following the launch of the surveys 592 online records were submitted, of which 24 were confirmed as *H. axyridis* (Figure 2 and 3), 174 were verified as native coccinellids and the remainder are currently unverified (Figure 3). It appears that many members of the public have been stimulated to look out for ladybirds, have noticed less familiar native species for the first time and suspected them to be *H. axyridis.* The number of verified *H. axyridis* reports is expected to rise as the spring dispersal continues and the breeding period begins.

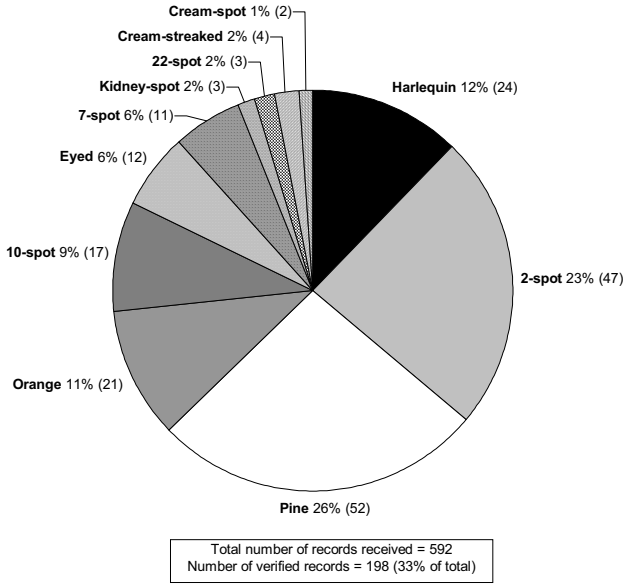


Figure 3: Percentage and actual number (in brackets) of verified ladybird records by species received from the UK public by the Harlequin Ladybird Survey from 15th March 2005 to 19th April 2005

(Harlequin = *Harmonia axyridis*; 2-spot = *Adalia 2-punctata*; Pine = *Exochomus 4-pustulatus*; Orange = *Halyzia 16-guttata*; 10-spot = *Adalia 10-punctata*; Eyed = *Anatis ocellata*; 7-spot = *Coccinella 7-punctata*; Kidney spot = *Chilocorus renipustulatus*; 22-spot = *Psyllobora 22-punctata*; Cream-streaked = *Harmonia 4-punctata*; Cream-spot = *Calvia 14-guttata*)

5.3. Anecdotal evidence of the UK public opinion on the arrival of H. axyridis

Ladybirds are extremely popular insects and so it is perhaps not surprising that the public response to these surveys has been great. The correspondence that has resulted from the publicity associated with the launch of the Harlequin Ladybird Survey in the UK has provided anecdotal evidence of the public's opinion on the arrival of *H. axyridis*. Undoubtedly the overwhelming response is of concern for the native fauna from a biodiversity perspective, with little consideration of the origins of *H. axyridis* as a biological control agent. However, the general concern for native species has highlighted the perceived importance of natural enemies, such as ladybirds, of insect pests as biological control agents. So, while to most people *H. axyridis* is an unwelcome arrival, this has not altered their affection for ladybirds. However, although there still appears to be wide support for biological control as a pest control strategy, the arrival of *H. axyridis* may have emphasized the different methods that can be employed and classical biological control may now be viewed more cautiously. Indeed some people have

expressed frustration that risk assessment and cost-benefit analysis have not prevented the use of *H. axyridis* in biological control programmes.

There have been a minority of people who have asked why the impact to our native fauna is a concern and whether in fact this is just a natural process of colonization by one species coupled with potential extinction of others. A similarly low number of people have recognized that *H. axyridis* may benefit agricultural systems and thus feel that it's arrival is advantageous. However, the overwhelming balance of public opinion is that *H. axyridis* represents a real threat to UK ecosystems.

5.4. Future plans

The Harlequin Ladybird Survey and the UK Ladybird Survey will continue to monitor ladybirds within the UK for at least the next five years. The data accumulated, along with historic data, will enable detailed evaluation of the direct and indirect effects of *H. axyridis* on native coccinellids and other insects. From this quantitative approach we will gain a greater understanding of the complex interactions between multiple species within the aphidophagous predatory guild with particular reference to an invasive species. Many studies have assessed the use of multiple natural enemies for biological control but generally on a small spatial scale (Roy and Pell, 2000). The UK Ladybird Survey, and projects generated from it, will enable multiple species interactions to be considered on much larger spatial and temporal scales. This will not be without its challenges but continued research in this area is critical to create a strategy for controlling this invasive species, protecting the native fauna and implementing sustainable strategies for pest management.

6. *Harmonia axyridis*: a global problem

Coccinellids have been used widely as classical biological control agents. In some cases their use has been highly successful as typified by the vedalia ladybird introduced to control cottony cushion scale insects in the Californian citrus industry in 1888 (Majerus, 1994). In other cases introduced coccinellids have failed to adequately control the target pest below economically damaging thresholds or, indeed, to thrive at all. Up to 1985, of 179 species of coccinellid introduced to North America only 18 became established (Gordon, 1985). However, perhaps the worst case scenario of biological control is an introduced species adversely affecting non-target species, as, for example, in the infamous case of cane toads in Australia. *Harmonia axyridis* is not the first introduced coccinellid to present a threat to the wider ecosystem. The 7-spot ladybird, *C. septempunctata* was repeatedly released in North America and the decline of the convergent ladybird, *Hippodamia convergens*, and two endangered lycaenid butterflies are now attributed to its success in establishing (Horn, 1991).

Invasive species, whether they are intentionally or unintentionally introduced, represent a global problem. However, even within Europe there is considerable variation in the regulation of introduced invertebrate biological control agents, from none at all to stringent. Cooperation and collaboration between countries both within Europe and beyond will undoubtedly accelerate progress and understanding of *H. axyridis* and other invasive species. Hopefully, lessons will be learnt before homogenization of species occurs on a global scale. The threat that voracious predators, such as *H. axyridis*, pose to indigenous species are an unacceptable consequence of biological control. The prevalence of *H. axyridis* around the world is testament

to its adaptability and competitive ability, both traits that ensure *H. axyridis* is successful in controlling pest insects. Unfortunately it is these same traits that also make it a threat to other species on a global scale. The high profile of *H. axyridis* as both an invasive species and a biological control agent may hinder the promotion of modern biological control but safety and sustainability must be the prime consideration. Biological control is and will remain an essential component of sustainable agriculture, but the distinction between a successful biological control agent and an invasive species can be narrow.

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