A review of the biology of the invasive harlequin ladybird *Harmonia axyridis* (Pallas, 1773) (Coleoptera, Coccinellidae)

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A review of the biology of the invasive ladybird, *Harmonia axyridis* Pallas 1773, is given. The species was recorded in 2006 for the first time in Norway, and its potential for establishment in Norway is discussed. The specimen was found on horticultural plants imported from Aalsmeer in the Netherlands to Oslo, Norway. *H. axyridis* originates from East-Asia. The species is known to be a voracious predator on aphids and has been extensively used as a biological control agent in both North America and Europe. In later years, however, a number of negative impacts on the environment and biodiversity have been reported. The species was assessed as a potential bio-control agent for use in Norwegian greenhouses in 2001. The assessment was negative with respect to import and commercial use in Norway. It was concluded that *H. axyridis* might survive and become established outdoors and thereby pose a risk to the environment. Recent experiences from the UK have shown that *H. axyridis* compasses several of the traits characterizing a successful invasive alien species. More record of the species in Norway may succeed after this first occurrence. It is likely that this species will survive outdoors, at least in the southern parts of Norway.

Key words: *Harmonia axyridis*, invasive alien species, first record in Norway, global trade, biological control, biodiversity.

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INTRODUCTION

A study aiming to get an overview of the amount and diversity of organisms/species entering Norway as stowaways on plant commodities imported for outdoor use was conducted in 2006. Samples from consignments of horticultural plants newly imported from different countries in Europe were examined and investigated as part of a master thesis (Staverløkk 2006). During this study the invasive alien ladybird *Harmonia axyridis* Pallas 1773 (Coleoptera: Coccinellidae) was recorded. This beetle is of great concern in many European countries. The species is synonymous to *Leis axyridis* (Iablokof-Khnzorian 1982), and is known under several common names like Multicoloured Asian Ladybird (US), Halloween Beetle (US) and Harlequin ladybird (UK).

H. axyridis originates from Central- and East Asia

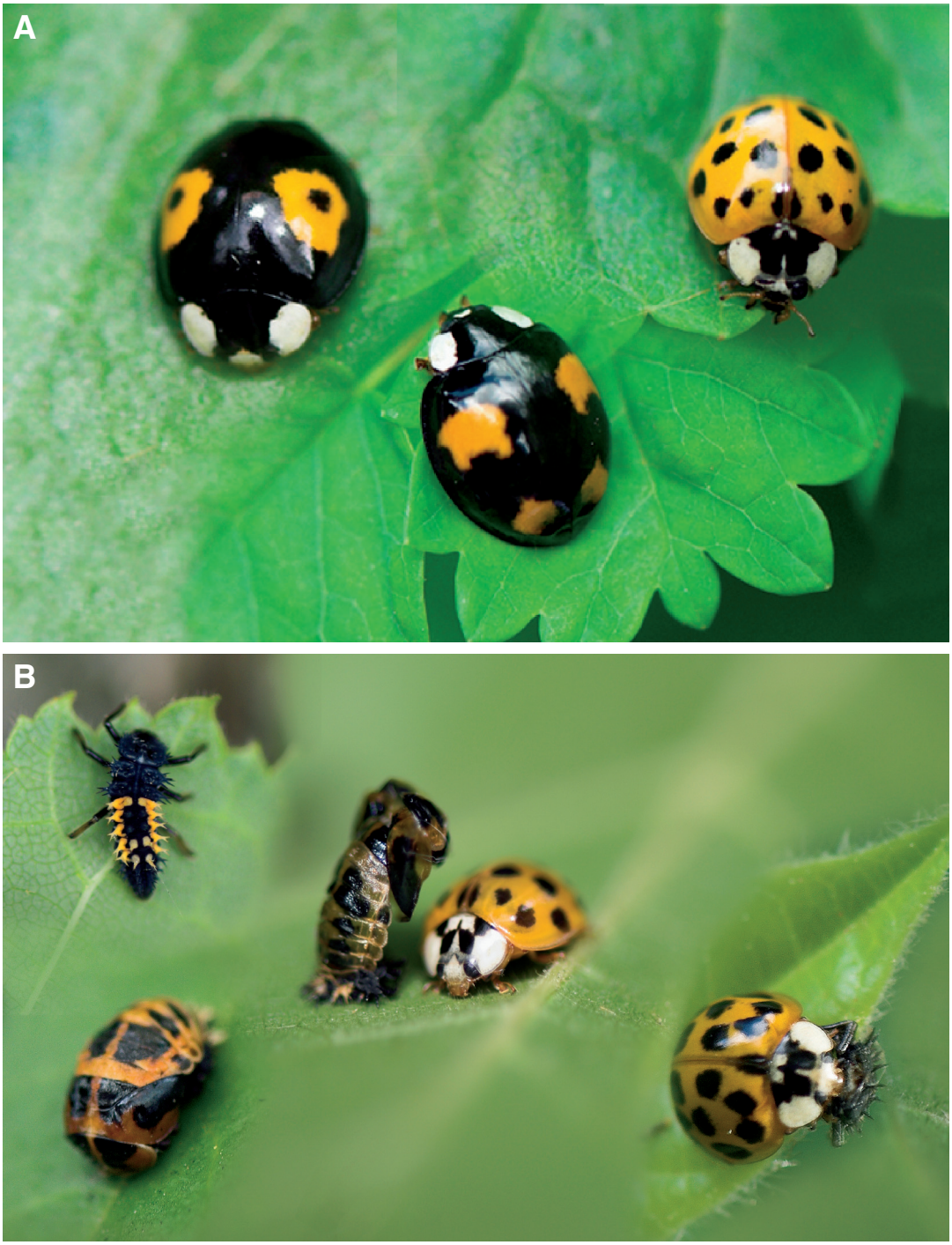

Figure 1. A) Three of the most common morphological forms of *Harmonia axyridis* found in Europe. From left: f. *conspicua*, f. *spectabilis* and f. *succinea*. B) Different development stages of *H. axyridis*. Larva (upper left), pupa (lower left), and newly hatched adult (middle). The adult to the right is eating a ladybird larva (Photo: Arnstein Staverløkk).

(Iablokoff-Khnzorian 1982) and Japan (Honek 1996), and has been introduced as a biological control agent in many parts of the world. The species is known to be a voracious predator on aphids and has been extensively used as a biological control agent in both North America and Europe (Gordon 1985, Ferran et al. 1996, Katsoyannos et al. 1997, EPPO 2006). The later years, however, a number of negative impacts on the environment and biodiversity have been reported. The species was assessed as a potential bio-control agent for use in Norwegian greenhouses in 2001 (Statens landbrukstilsyn 2001). The outcome of the assessment was negative with respect to import and commercial use in Norway. It was concluded that *H. axyridis* might survive and become established outdoors and thereby pose a risk to the environment. The following review presents the biological characteristics which show that this beetle is a potential threat for the Norwegian fauna.

RESULTS AND DISCUSSION

The ladybird *H. axyridis* was discovered 19 April 2006 in Oslo, travelling as a stowaway on horticultural plants (*Thuja* sp.) imported from Aalsmeer in the Netherlands to Norway (Staverløkk 2006) (Figure 1). This record is the first report of this species in Norway. The specimen had the *succinea* -form which is one of the morphological forms (morphs) found in the populations established in Europe (Majerus et al. 2006). It was a female, full of eggs.

Identification and detection

H. axyridis is about 5-8 mm long, ovally shaped and has a very variable appearance, which can make it difficult to distinguish from other ladybirds. The species shows wide morphological plasticity and varies a lot in colours of the elytra and the pronotum. It is represented by more than 100 morphs (Iablokoff-Khnzorian 1982). Ground colours of the elytra differ between pale yellow, orange, orange-red, red or black. It can be painted with orange-red or black spots or in some cases a sort of grid pattern. The most common morphs found in Great Britain and in Europe are orange with 15-21 black dots or black with 2 or 4 orange or red spots. Pronotum is mostly white or creamy with up to 5 spots or fused lateral spots forming 2 curved lines, M-shaped mark, or a solid trapezoid. Other characteristics are the wide keel at the back and that the legs of this species are almost always brown (The UK Ladybird Survey 2007).

A few different morphs occur on the British Isles and in Europe: f. *succinea* are orange or red with zero to 21 black spots, f. *axyridis* which has an orange colour and a grid-like black pattern on the elytra, f. *conspicua* and f. *spectabilis* which are black/melanic, with two and four large orange/red spots, respectively (Majerus et al. 2006) (Figure 1A).

Geographical distribution, intentional and accidental introductions

The first release as a biological control agent is known from North America in 1916 (Gordon 1985). The first established population in the US was documented in 1988 (LaMana & Miller 1996). Scientists still discuss whether this population has established as a result of frequent release or through accidentally introduction with import (Tedders & Schaefer 1994). During a period of 20 years *H. axyridis* has spread across great distances and established in new areas in USA and in Canada where it is well established and has become the most common ladybird species (Hesler et al. 2001). In 2001 it was recorded in South-America (de Almeida & da Silva 2002). Koch et al. (2006) used the CLIMEX model and a biome model to assess the bioclimatic potential for this species in South America, and concluded that both climate and habitat are favourable for *H. axyridis* to establish in the region.

H. axyridis was first introduced to Europe in 1964 (EPPO 2006), and used commercially in biological control of various aphid species since 1982 (Ferran et al. 1996, Katsoyannos et al. 1997, Iperti & Bertand 2001). In Belgium they started to use the species commercially in 1997, but there were no reports of the beetle in the wild until 2001 (Adriaens et al. 2003). Since then, the numbers

have increased steadily. In the UK it has not been approved for use in biological control. The first individual was found 19 September 2004 (Majerus et al. 2006). KOPPERT in the Netherlands and BioPlant in Denmark sold and distributed *H. axyridis* until the end of 2002/ beginning of 2003 when they stopped after rising amounts of reports on negative impacts on the environment (pers. comm. L.O.G A/S and BioPlant). The species is confirmed established in France, Belgium, Netherlands, Germany, Luxemburg, Italy and UK (Roy et al. 2006).

Potential for establishment in Norway

Hibernation

The species is generally considered bivoltine in much of Asia, North America (LaMana & Miller 1996; Koch & Hutchinson 2003) and Europe (Trouve et al. 1997). However, up to four or five generations per year have been observed (Katsoyannos et al. 1997). In late-winter or early-spring, the adults switch from diapause to a quiescent state and upon arrival of warmer temperatures in spring they mate and disperse from their overwintering sites (LaMana & Miller 1996, Iperti & Bertand 2001). The minimum temperature for eggs to hatch is 11.2 °C with an American population (LaMana & Miller 1998) and 10.5 °C for a French population (Schanderl et al. 1985).

During the summer, beetles may spend time in quiescence as a response to uncomfortable conditions (Sakurai et al. 1992) and around October/November they start to migrate to their overwintering sites (Kidd et al. 1995, LaMana & Miller 1996). In Japan *H. axyridis* acclimates to winter by decreasing its supercooling point (the temperature when the body fluids freeze) rapidly in November to about –18 °C between December and February (Watanabe 2002). Diapause is entered with an empty digestive tract, enlarged fat body, and most females overwinter unmated (Nalepa et al. 1996, Iperti & Bertand 2001). Koch et al. (2004) tested the cold tolerance on different stages of *H. axyridis* in North America. They also investigated the supercooling point for each stage and found it to be -27.0 °C, -21.3 °C, -14.17 °C and -11.9 °C for eggs, larvae, pupae, and imago, respectively. Populations of *H. axyridis* also occur in areas like northern United States and southern Canada (Coderre et al. 1995, Koch & Hutchinson 2003,) that have temperatures below the super-cooling point. This may be due to more favourable microclimates (Koch et al. 2004).

*H. axyridi*s is capable to survive the British winter as it is well established there. Roy et al. (2006) predicted that by 2008 *H. axyridis* will have spread across mainland Britain. The adaptability of *H. axyridis* to climate change will probably provide it with a competitive advantage over less adaptable ladybirds in Great Britain as well (Roy et al. 2006). It is likely that the same will apply for the species in Norway. The fact that this insect can spend the winter indoors is an adaptation to cold climate. In addition, the ability to survive relatively low temperatures makes *H. axyridis* a species likely to become established in Norway, if introduced.

Diet

H. axyridis has a wide diet and although it feeds mostly on aphids in all stages, it can successfully complete its lifecycle with the supply of scale insects (Coccidae), adelgids (Adelgidae), psyllids (Psyllidae) and spidermites (Tetranychidae) (Tedders & Schaefer 1994, Hodek 1996, Lucas et al. 1997, Koch 2003). This species is able to reduce aphid numbers below economically damaging levels within many crop systems and thereby reducing the dependency of chemical pesticides (Roy et al. 2006). Koch et al. (2006) lists arboreal hosts (trees and shrubs) and associated preys utilized by *H. axyridis*. More than 30 different species of aphids are listed and also a few species of Psyllidae, of which several are present in Norway. Koch et al. (2003) identified *H. axyridis* as a predator also of the Monarch butterfly, *Danaus plexippus* L., an aposematic species well known for its seasonal migrating behaviour in North America and Mexico.

Competition

H. axyridis is a good colonist and very competitive because of its wide diet and the many different

morphological traits. This gives the species a genetic variation which can be very beneficial in new environments (Grill et al. 1997). In the USA the ladybird has established and dispersed in several states which reflect its skills to adapt to new habitats, climates, resources and to undergo selection (Grill et al. 1997). Its voracious appetite competes with other aphidophagous insects (Michaud 2000). *H. axyridis* can therefore become a threat for native ladybirds including *A. bipunctata* and *C. septempunctata* (Adriaens et al. 2003), which are common species in Norway, and for other predators of aphids, like lacewings (*Chrysoperla* spp.), as well as of parasitoids. *H. axyridis* may have a direct impact on aphid parasitoids because both adult and larvae of *H. axyridis* feed on parasitized aphids that have not yet mummified (Nakata 1995). It becomes an intraguild predator that eats individuals and species that benefit from the same food source as itself.

Natural enemies

Several natural enemies (e.g. parasitoids) of *H. axyridis* are reported from its native range and may be the reason why *H. axyridis* is not a problem/nuisance in Asia. According to Nechayev & Kuznetsov in Koch (2003) eight species of birds are reported preying on *H. axyridis* in Russia. Park et al. in Koch (2003) reports *Dinocampus coccinellae* Schrank (Hymenoptera: Braconidae) as a natural enemy of *H. axyridis* in Korea. Indigenous natural enemies of *H. axyridis* in Norway have so far not been investigated, but since *H. axyridis* is an alien species it is reason to believe that the number of natural enemies will be very limited.

Dispersal potential

Introductions of *H. axyridis* to regions outside its native range have been extensive. Many scientists have contributed to a big collection of scientific papers about the ecology, behaviour and distribution of this invasive ladybird. It should also be noted that the spread of *H. axyridis* has not only occurred because of its use in biological control, but also undocumented commercial releases, unintentional introductions, and the species own dispersal capacity (i.e. flight) have certainly contributed to the extent of its invasion and success (Koch et al. 2006).

Recent experiences from the UK have shown that *H. axyridis* possesses several of the traits characterizing a successful invasive alien species. After the first record in UK in 2004, a comprehensive survey was initiated. The survey shows how the Harlequin ladybird has conquered most of the island and continues to spread. The beetles can now be found almost all over the country and people report that they find them inside their houses (UK Ladybird Survey 2007).

The distribution of *H. axyridis* in North America shows that this species can establish itself over large areas in a few years from introduction. In many states in USA, *H. axyridis* has become the most common aphidophagous ladybird of the approximately 475 species of Coccinellidae in North America north of Mexico (Gordon 1985, Hesler et al. 2001). Numbers of native ladybirds may decrease and go locally extinct because of displacement and intraguild predation by *H. axyridis* (Colunga-Garcia & Gage 1998). One of the problems using this species in biological control is that the adults are unwilling to stay on the plants after being released. Adults can fly long distances while tracking new aphid colonies to lay their eggs. Therefore, Trouve et al. (1997) considered the larval stage the best for biological control. In order to not give up the use of adults for biocontrol, researchers managed to create a flightless variant. It had the same biology but spent more time foraging (Tourniaire et al. 1999).

Dispersal from Denmark to Norway by crossing the Skagerak by flight might be too far even for this ladybird. *H. axyridis* is not yet recorded in Denmark or Sweden, but has been used as a bio-control agent in Danish greenhouses. The most likely way that the species can enter Norway, is through accidental import on plant commodities. It may then spread across Norway through the domestic distribution of plants, and after establishment continue to spread over shorter distances by self dispersal.

Potential threats in Norway

The ecological price for introducing a new species without fully knowing the consequences can be very high. *H. axyridis* has a great ability to fly long distances and appears to be very adapted to track aphid populations in space and time. The same applies when in search for an overwintering site (With et al. 2002). If *H. axyridis* become established in Norway, it may change the existing composition of ladybird species, and it may also become a pest and a nuisance for humans (Huelsman et al. 2002). In Norway there are 54 known species of ladybirds, some of which have been reported to decline in numbers in other countries where *H. axyridis* has been introduced. This could also pose a threat to the eight species of Coccinellidae listed on the recently released National Red List of endangered species (Kålås et al. 2006). Moreover, *H. axyridis* is mentioned in the Black List as an example of a species that is a threat to the environment (Gederaas et al. 2007). The present record may only be the first in a number of such, as it is likely that this species will survive outdoors at least in the southern parts of Norway.

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