# Invasion history of *Harmonia axyridis* (Pallas, 1773) (Coleoptera: Coccinellidae) in Ecuador

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## Abstract

*Harmonia axyridis* is a ladybird extensively used around the world for biological control of agricultural pest. However, it has become invasive in several countries, producing negative ecological and socio-economic impacts. Herein, we review the invasion history of the Harlequin Ladybird *Harmonia axyridis* (Pallas, 1773) in Ecuador. Although first reported in Ecuador in 2012, museum specimens date back to 2001 and it is currently established across the country, especially along the Andean region. Due to its invasive nature, further studies are urgently needed to evaluate possible impacts of *H. axyridis* on the Ecuadorian biodiversity and agroindustry.

**Key words:** Andes; Coccinellinae; distribution; introduced species; ladybird; new records; range extension.

## INTRODUCTION

Numerous species have arrived to regions they would have never reached on their own thanks to human-mediated processes (Boivin et al., 2016, Ricciardi, 2007). Although many non-native species are unable to thrive in new environments, some are successful and become invasive by establishing fast-growing, spreading populations. Invasive species have been described as major drivers of current biodiversity changes due to their contribution to biota homogenization, alteration of biological communities and ecosystem functions, and socio-economic impacts on humans (Chapin III et al., 2000; Daszak et al., 2000; Crooks, 2002; O'Dowd et al., 2003; Clavero & García-Berthou, 2005; Mace et al., 2005; Doody et al., 2009; Pejchar & Mooney, 2009; Ricciardi et al., 2013; Simberloff et al., 2013; Bellard et al., 2016; Doherty et al., 2016; Cisneros-Heredia, 2018).

*Harmonia axyridis* (Pallas, 1773), commonly referred to as Harlequin Ladybird or Asian Multicolored Ladybeetle, is a member of the family Coccinellidae native to East Asia (Orlova-Bienkowskaja, Ukrainsky & Brown, 2015). It has been deliberately translocated as a biological control in America, Europe and Africa since the beginning of the 20$^{th}$ century, becoming invasive and establishing naturalized and expanding populations in the three continents (Lombaert et al.,

2010; Brown et al., 2011). It is a successful invader due to its wide dietary range, ability to establish and disperse, and robustness and flexibility of its immune system (Roy, Brown & Majerus, 2006; Vilcinskas, Mukherjee & Vogel, 2013). *Harmonia axyridis* is considered as the most invasive ladybird on Earth (Roy, Brown & Majerus, 2006).

*Harmonia axyridis* is a voracious predator of agricultural pests, consuming soft-bodied Sternorrhyncha hemipterans as essential preys, i.e. aphids, coccids, psyllids, and adelgids (Roy, Brown & Majerus, 2006). However, *H. axyridis* has a wider dietary range and is an interguild and intraguild polyphagous predator, being able to consume immature stages of coccinellids and other coleopterans, lepidopterans, neuropterans, dipterans, tetranychid mites, and plant material such as fruits, pollen, nectar, leaves and seeds (Koch et al., 2004; Roy & Wajnberg, 2008; Koch & Galvan, 2008; Moser, Harwood & Obrycki, 2008; Martins et al., 2009; Lucas, 2012; Michaud, 2012). In general, *H. axyridis* is considered one of the top predators in aphidophagous and coccidophagous guilds, largely free from predation pressure, and regulated more by bottom-up than top-down forces (Lucas, 2012). *Harmonia axyridis* seems to dominate confrontations with other coccinellid species, exerting a strong intraguild predation pressure (Lucas, 2012). Due to its polyphagy and guild interactions, non-native populations of *H. axyridis* have adverse effects on native biodiversity and agroindustry by attacking non-target arthropods, modifying the structure and dynamics of invertebrate assemblages, replacing or marginalising native coccinellids by competition and predation, and feeding on commercial fruits or damaging agricultural products (Koch, 2003; Koch et al., 2004; Koch & Galvan, 2008; Honěk, 2012; Lucas, 2012).

In America, *Harmonia axyridis* was deliberately introduced as a biocontrol agent in several countries and has dispersed and established naturalized populations throughout the continent (Brown et al., 2011). It was first recorded in Ecuador in 2012; but geographic and ecological data are scarce and, to the best of our knowledge, only three localities on the southern Pacific lowlands of the country have been published in scientific literature (González & Kondo, 2012; Cornejo & González, 2015). Herein, we discuss about the distribution, natural history, and introduction history of *Harmonia axyridis* in Ecuador, evidencing that it has been present at least since 2004 and is currently widespread across the country.

## MATERIALS & METHODS

We conducted surveys at different localities across Ecuador (Table 1, Fig. 1). All specimens were found by searching vegetation to look for adults and larvae. Collected specimens were euthanized by immersion in 70% ethanol or by placing in a killing jar and stored. An Olympus Research Stereomicroscope System SZX16 outfitted with an Olympus DP73 digital colour camera was used to observe specimens. Collected specimens are deposited at the Museo de Zoología, Laboratorio de Zoología Terrestre, Universidad San Francisco de Quito, Ecuador (ZUSFQ). Research permits were issued by Ministerio de Ambiente del Ecuador, 001-16IC-FLO-FAU-DNB/MA, 018-2017-IC-FAU-DNB/MAE, 019-2018-IC-FAU-DNB/MAE, and 006-2015-FAU-DPAP-MA. In addition, we reviewed the entomological collections of Museo de Zoología, Pontificia Universidad Católica del Ecuador, Quito (QCAZ), and Instituto Nacional de Biodiversidad INABIO, Quito (MECN).

Published information on *Harmonia axyridis* in Ecuador was synthesised based on a literature review using the library systems of King's College London and Universidad San Francisco de Quito USFQ, and Google Scholar™ scholarly text search (https://scholar.google.com). Relevant references were gathered using the search terms 'Coccinellidae', 'Harmonia', '*Harmonia axyridis*', 'Mariquita', 'Ladybird', 'Ladybug', and 'Lady beetle', each one combined with 'Ecuador' by the Boolean operator 'AND'. Because *Harmonia axyridis* has a diagnostic colouration pattern that allows its identification in photographs, we assembled data from photographic vouchers using the search engines of Flickr™ (https://www.flickr.com, by Yahoo!) and iNaturalist.org™ (http://www.inaturalist.org, by California Academy of Sciences and the National Geographic Society) through GeoCat (Bachman et al., 2011; http://geocat.kew.org/) using the same search terms used for text searches. All searches were run on 10 February 2019 using on-site search engines and were not limited by study type, study design, or language. All localities, based on literature, museum, or photographic records, were georeferenced manually in Google Earth™ mapping service (7.3.1.5491 release by Google, Inc. on July 2018) based on direct information (coordinates and altitudinal data) when available, and additional data relevant to obtain an accurate and precise positioning, including catalogue and field notes, following recommendations by Wieczorek et al. (2004). All localities were reviewed and validated individually, and coordinates were amended when incorrectly georeferenced in the source (Table

1). We determined the position most closely related with the locality description using toponymic information based on the Geographic Names Database, containing official standard names approved by the United States Board on Geographic Names and maintained by the National Geospatial-Intelligence Agency (http://geonames.nga.mil/gns/html/), OpenMapStreet data available under the Open Database Licence (http://www.openstreetmap.org), and gazetteers for Ecuador (Brown, 1941; Peters, 1955; Lynch & Duellman, 1997).

Specimens herein reported were identified as *Harmonia axyridis* by its characteristic morphology (Fig. 2), including: upper surfaces of elytra not hairy, distinct transverse fold at rear of elytra, underside of abdomen at least partially orange, brown to orange legs (Koch, 2003; Roy et al. 2016). One phenotypic form was found: f. *succinea*, with ground colour of pronotum white to light brown with M-shaped black marks, ground colour of elytra bright orange, usually with nine black elytral spots (2-3-3-1) and a scutellary spot (Dobzhansky, 1933; Tan & Li, 1934; Koch, 2003; Brown et al., 2008; Roy et al., 2013; Roy et al., 2016).

## RESULTS

In total, we collected information for 183 records of *Harmonia axyridis* from 56 localities in Ecuador (Table 1, Fig. 1), including: 144 museum specimens (107 at ZSFQ, 37 at QCAZ, none at MECN), five photographic records from Flickr, 16 records in iNaturalist, four observations, and 14 specimens reported in the literature (González & Kondo, 2012; Cornejo & González, 2015; Guamán Montaño, 2017).

Our study reveals that *Harmonia axyridis* is established in all main biogeographic areas of Ecuador, from sea level to at least 4020 m elevation, across 13 provinces (administrative divisions) (Table 1, Fig. 1). The only regions where we did not found records are the southern Amazonian lowlands and the Galapagos Archipelago. The first specimens found were collected on both geographical extremes of Ecuador: in 2004 at Mindo, northwestern Ecuador, and in 2007 at Loja, in southwestern Ecuador (Table 1). Both localities are separated by about 450 km.

At least 33 localities are mid-size towns and large cities, where *Harmonia axyridis* occupies gardens and urban and suburban green spaces dominated by non-native plants. Other localities

correspond to agricultural areas or natural environments, including protected areas. In areas covered by native vegetation, *H. axyridis* was mainly collected on road borders. At least one record, at Estación Científica Yasuní, may correspond to a hitchhiking individual, since no established population in the Amazonian lowlands has been confirmed.

Since 2015, we surveyed periodically the population of *Harmonia axyridis* at Cumbayá, a suburban parish of Quito, capital city of Ecuador. *Harmonia axyridis* is well established in Cumbayá, with several subpopulations detected in gardens and small urban and suburban green areas. They are usually associated with the following plants (local names in parentheses): *Hibiscus rosa-sinensis* (Cucarda), *Senna multiglandulosa* (Chinchín), *Citrus* x *limon* (Limonero), *Prunus setorina* (Capulí), *Prunus persica* (Peach), *Lantana camara* (Tupirrosa or Supirrosa), and *Ficus benjamina* (Ficus). We found five coccinellid species in sympatry in gardens, urban/suburban green areas and agricultural lands of Cumbayá: *Harmonia axyridis*, *Hippodamia convergens*, *Mulsantina mexicana*, *Cheilomenes sexmaculata* and *Rodolia cardinalis*. *Harmonia axyridis* was the most common species in gardens and urban/suburban green areas, but it was not found in agricultural areas, where *H. convergens* was dominant. Only *R. cardilanis* was found in syntopy with *H. axyridis*. By 2017, *H. convergens* is almost absent in most gardens and urban/surburban areas, remaining common only in agricultural areas. *C. sexmaculata*, an apparently recent arrival—first recorded in the area on 2017, is nowadays becoming the second most common coccinellid in urban/suburban green areas of Cumbayá, although still with a patchy distribution.

The following coccinellids have been found in sympatry with *Harmonia axyridis* at different localities: *Brachiacantha* sp. cf. *anita* (Mindo), *Cheilomenes sexmaculata* (Quito, Cumbayá), *Cycloneda ecuadorica* (Guajalito, San Vicente), *C. emarginata* (Guajalito, Loja), *C. sanguinea* (San Vicente), *Epilachna monovittata* (Guajalito), *E. flavofasciata* (Guajalito), *E. paenulata* (Quito, Mindo), *Hippodamia convergens* (Quito, Lumbisí, Cumbayá, Yaruquí, Guajalito, San Vicente, Mindo, Loja), *Mulsantina mexicana* (Cumbayá, Yaruquí, Guajalito), *Neda norrisi* (San Antonio de Pichincha), and *Rodolia cardinalis* (San Antonio de Pichincha, Cumbayá).

**Comentado [PL1]:** And about the parasitoids? They were not found? This should be discussed

## DISCUSSION

In America, the first translocation of *Harmonia axyridis* was to the USA in 1916, and recurrent introductions to that country occurred between 1964 and 1982 (Gordon, 1985). The first established feral populations were recorded in 1988 in eastern USA (Chapin & Brou, 1991), in 1991 in western USA (LaMana & Miller, 1996), and in 1994 in Canada (Coderre et al., 1995). The two USA populations originated from independent introductions from the species' native range (Lombaert et al., 2010), and the Canadian population apparently spread from eastern USA (McCorquodale, 1998). All subsequent successful introductions of *H. axyridis* across America have seemingly sourced from eastern USA (Lombaert et al., 2010). Mexican populations descend from eastern USA stocks deliberately released in northern Mexico (ca. 1997) and southeastern Mexico (1999–early 2000s) (Quiñones Pando & Tarango Rivero, 2005; Barrera & López-Arroyo, 2007). First translocations to Argentina (1986) and Chile (1998) used parental stocks from France but were unsuccessful in establishing populations (García, Becerra & Reising, 1999; Saini, 2004; Grez et al., 2010). Naturalised populations reported in Argentina in 2001, southern Brazil in 2002, and Chile in 2003 descend from at least two different eastern USA stocks (Almeida & Silva, 2002; Saini, 2004; Grez et al., 2010; Lombaert et al., 2010). The oldest known naturalised populations in South America were established in Colombia, where *H. axyridis* was first collected in 1989 (Kondo & González, 2013). Since *Harmonia axyridis* was extensively raised and shipped in the USA in the 1980s and 1990s (Tedders & Schaefer, 1994), and based on available dates, Colombian populations may also descend from eastern USA stock. It is probable that unrecorded international shipments were sent to Colombia, Argentina, and Chile—possibly to private farmers, thus the absence of public records. Subsequent South American records come from Ecuador (2004, this study), Paraguay (2006, Silvie et al., 2007), Uruguay (2009, Nedvěd & Krejčík, 2011), Peru (ca. 2010, Grez et al., 2010), and Venezuela (ca. 2014, Solano & Arcaya, 2014). It has not been formally recorded in Central America, Guyana, Suriname and Bolivia (Camacho-Cervantes, Ortega-Iturriaga & del-Val, 2017). However, established populations may occur at least in southern Mexico (Saenz Garcia, 2015; Ramírez Marcial, 2016), Guatemala (Amador da Silva, 2017), and Costa Rica (Cralingworld, 2009; Spring,2011; Mclaren, 2015).

All published records of *Harmonia axyridis* in Ecuador were reported from southern Ecuador. González & Kondo (2012) presented the first reports of *H. axyridis* in the country, based on 11 specimens collected in 2012 in deciduous forests on La Ceiba and Laipuna natural reserves (762

and 828 m elevation, respectively), province of Loja, extreme southwestern lowlands of Ecuador. Cornejo & González (2015) reported the species from mangroves on Santay island (at sea level), province of Guayas, southwestern Ecuador. González (2015) reported *H. axyridis* from the provinces of Azuay, Guayas and Loja, but without referencing any voucher specimen from Azuay. Guamán Montaño (2017) presented photographs of *H. axyridis* from El Pangui (830 m elevation), province of Zamora-Chinchipe, providing the first reports on the south-eastern slopes of the Andes of Ecuador.

Extensive and intensive entomological studies conducted in northern Ecuador up to 2001 did not recorded *Harmonia axyridis* (e.g., Cardona et al., 2005; Carvajal et al., 2005). Thus, the first naturalised populations of *H. axyridis* in Ecuador probably got established between 2001 and 2004. Intentional introduction of *H. axyridis* in Ecuador seems probable. Introduction of ladybirds in Ecuador has a long history in Ecuador, for example, in 1978, official national authorities released 24 million individuals of *Hippodamia convergens* in the city of Quito and surroundings as an attempt to control *Icerya purchasi* (Molineros Andrade, 1984). However, it is also likely that Ecuadorian populations spread from southern Colombia, since the oldest Colombian populations occurred very close to the Ecuadorian border (Kondo & González, 2013). The presence of earliest Ecuadorian localities on opposite sides of the country (Mindo and Loja) and the absence of geographically intermediate records could suggest that Ecuadorian populations have two independent origins. However, museum records are biased due to limited collection efforts in the central provinces of Ecuador. Furthermore, spread rate of *H. axyridis* may be extremely fast and compensate for the distance between the localities (100 km/year in the UK, 200 km/year in Slovakia, Roy et al. 2016; 185 km/year in Chile, Grez et al., 2016; 442 km/year in USA-Canada, McCorquodale, 1998; 500 km/year in South Africa, Stals, 2010). If southern Ecuadorian population would be demonstrated to have an independent origin, they may have given origin to the northern Peru populations—which remained unrecorded during extensive surveys in 2006 (Miró-Agurto & Castillo-Carrillo, 2010) and became established around 2010 (Grez et al., 2010).

Populations of *Harmonia axyridis* in Ecuador are established at elevations between sea level and 4020 m, the highest record worldwide, 500 m higher than the upper elevational ranges reported

by Grez et al. (2017) and González et al. (2018). Lowland records mainly come from the Pacific lowlands and western Andean slopes, but also from the Amazonian lowlands. The Andean region was predicted as suitable for the expansion of *H. axyridis* by distribution models analysed by Koch et al. (2006) and Poutsma et al. (2007), which although predicted the expansion of *H. axyridis* across different habitat of America, their models did not predict lowland forest. Interestingly, Ecuadorian records come from a variety of habitats, including cloud montane forest and dry montane and lowland forest, and across the urban-suburban matrix. However, the most extensive and dense populations were found in urban and suburban areas.

It is likely that *Harmonia axyridis* will spread across most of Ecuador, especially in urban and agricultural environments. Establishment of *H. axyridis* may significantly impact predatory arthropods guilds (Lucas et al. 2002, Koch 2003, Koch & Galvan 2008, Ducatti et al. 2017); having varied impacts on the diverse South American fauna of coccinellids due to competition, exclusion, and intraguild predation. Changes in the predatory arthropod guilds may interfere with invertebrate population dynamics, potentially impacting agricultural pests (Lucas et al. 2002, Pervez & Omkar 2006). In addition, since it feeds opportunistically on damaged fruit when prey is scarce (Koch et al. 2004), *H. axyridis* may impact fruit production. Unfortunately, information on the coccinellids of Ecuador is fragmentary. It is important to increase research on the diversity and population ecology of coccinellids of Ecuador, including ecological relationships between native and non-native arthropod species across urban-agricultural-natural matrices, in order to evaluate the impacts of *H. axyridis* and other non-native species in the country.

Excluído: , Koch & Galvan 2008

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