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INVASION NOTE

Citizen science reveals the distribution of the invasive harlequin ladybird (*Harmonia axyridis* Pallas) in Argentina

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Abstract The harlequin ladybird (*Harmonia axyridis*) was introduced in numerous countries around the world as a biological control agent but nowadays it is considered as a pest itself. It is a highly invasive species that has negative impacts on native biodiversity, may affect some crops, and causes a nuisance to humans. Despite its relevance worldwide, the invasion by *H. axyridis* in South America has received little attention. Here we used a citizen science approach to study the distribution of *H. axyridis* in Argentina where the species was intentionally introduced in 1986. We also informally tested and evaluated the preferences for different methods for reporting records: iNaturalist website, Google form, email, WhatsApp, and Facebook. Most records were reported through WhatsApp and iNaturalist. We found that *H. axyridis* is widely distributed in Argentina but there are large gaps, particularly in arid regions. The invasion seems to be recent in the south of the country. Citizen science is a valuable tool for mapping invasive alien species in a large country like Argentina, and will help to monitor the continuous expansion of *H. axyridis*.

Keywords Alien species · Biological invasion · Coccinellidae · iNaturalist · Pampa · Patagonia

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Introduction

Invasive alien species are considered one of the major drivers of biodiversity loss with serious impacts on not only ecology but also economies and human health (Díaz et al. 2019). *Harmonia axyridis* (Pallas) (Coleoptera, Coccinellidae) is a highly invasive alien species that is widely distributed worldwide (Camacho-Cervantes et al. 2017; Roy et al. 2016). It is native to Asia and has been introduced as a biological control agent in many countries and also accidentally in many others. Nowadays it has established populations in at least 59 countries outside its native range (Camacho-Cervantes et al. 2017; Roy et al. 2016) and it is found on all continents except Australia and Antarctica. This species has negative impacts on native biodiversity (Brown and Roy 2018; Grez et al. 2016) and it might affect some crops and the wine industry (Ameixa et al.

2019; Koch and Galvan 2008). It usually causes a nuisance to humans by overwintering inside houses in large numbers, and some allergic reactions and bites have been reported (Roy et al. 2016). Today, there is general consensus amongst the scientific community that the negative impacts of *H. axyridis* outweigh its benefits as a biological control agent (Camacho-Cervantes et al. 2017; Majerus et al. 2006). It is also regarded as a model species and as an opportunity for global collaborations for the understanding of invasion biology (Roy and Wajnberg 2008; Roy et al. 2016).

The invasion of *H. axyridis* has been intensively studied in Europe and North America (e.g. Ameixa et al. 2019; Brown et al. 2008; Koch and Galvan 2008), but detailed analysis of the distribution of the species in most of the countries in South America is rather outdated or scarce (but see Grez et al. 2016; Hiller and Haelewaters 2019). The species was introduced as a biological control agent through the 1980s and 1990s (Grez et al. 2016), and to date wild populations have been reported except in Bolivia, French Guiana, Guyana and Suriname (Brown et al. 2011; Camacho-Cervantes et al. 2017; Hiller and Haelewaters 2019; Montero and Vignaroli 2008; Olave 2016 and see Online Resource 1 for more details). However, the magnitude of its expansion in the countries where it is present has only been studied in Chile, where it shows a continuous distribution from ~ 29° S to ~ 42° S, being absent only in the northern desert and in southern Patagonia (Grez et al. 2016). For Argentina, the similarity in climatic conditions and biomes with regions where *H. axyridis* is native and climatic predictions suggest that almost the whole country is suitable for the establishment of the species (Koch and Galvan 2008; Koch et al. 2006; Poutsma et al. 2007).

Argentina is a large country (~ 2.7 million km^2) with a very diverse landscape. It extends ~ 33° in latitude (extreme latitudes: 21° 46′ S to 55° 03′ S) and ~ 20° in longitude (extreme longitudes 53° 38′ W to 73° 34′ W). It is mostly bordered by two strong barriers for the dispersal of many terrestrial species: The Andes to the West and the Atlantic Ocean to the East. It encompasses 14 biogeographic provinces (excluding the Falkland Islands) from the subtropical forests to the arid and cold Patagonian steppe (Arana et al. 2017), offering a wide range of conditions for the establishment of invasive species. *H. axyridis* was introduced into the Central-West region of Argentina in 1986 (García et al. 1999) and by 2001 it was detected around 1000 km away to the east (Buenos Aires; Saini 2004). By early June 2018 (before we widely promoted our project) the species was considered to be present only in a few localities from the centre of the country to ~ 39° S (Montero and Vignaroli 2008; Olave 2016; Saini 2004; Fig. 1a, Online Resource 2, Table 2a). Recently, Hiller and Haelewaters (2019) mapped the distribution of *H. axyridis* in Central and South America using Flickr, iNaturalist, and museum records. For Argentina, they found 24 records in Flickr (dated from 2006 to 2016) and 89 records in iNaturalist from which only 19 had been uploaded before the promotion of our project and only 15 represented independent points (four of them were duplicates). Taking these 43 records into account, the registered distribution of *H. axyridis* in Argentina by the end of May 2018, expanded from ~ 27° S to ~ 39° S (Fig. 1a). Documenting the distribution of *H. axyridis* in Argentina is the first step to evaluating its impact on native species and the economy and will also contribute to the general understanding of the ecology of this highly invasive alien species.

The study of the distribution of an insect in a large country using traditional techniques for biodiversity surveys would be extremely expensive and time-consuming. Citizen science is a powerful alternative to gather biodiversity data for wide geographical scales, and it is also a way of engaging people with science, increasing their awareness of environmental issues (Dickinson et al. 2012). Today, the extensive use of email, internet and social networks provides an unprecedented opportunity to reach people and receive information. In addition, engaging people in recording ladybirds is promising since these insects are usually attractive to the public. Indeed, the involvement of citizens in monitoring *H. axyridis* has provided invaluable data in many countries (e.g. Grez et al. 2016; Purse et al. 2015; Veran et al. 2016). Here, we used a citizen science approach to study the distribution of *H. axyridis* in Argentina to test our hypothesis that the species is widespread in the country. In addition, we evaluated the preferences of Argentinean citizens in using different methods for reporting occurrences of this species.

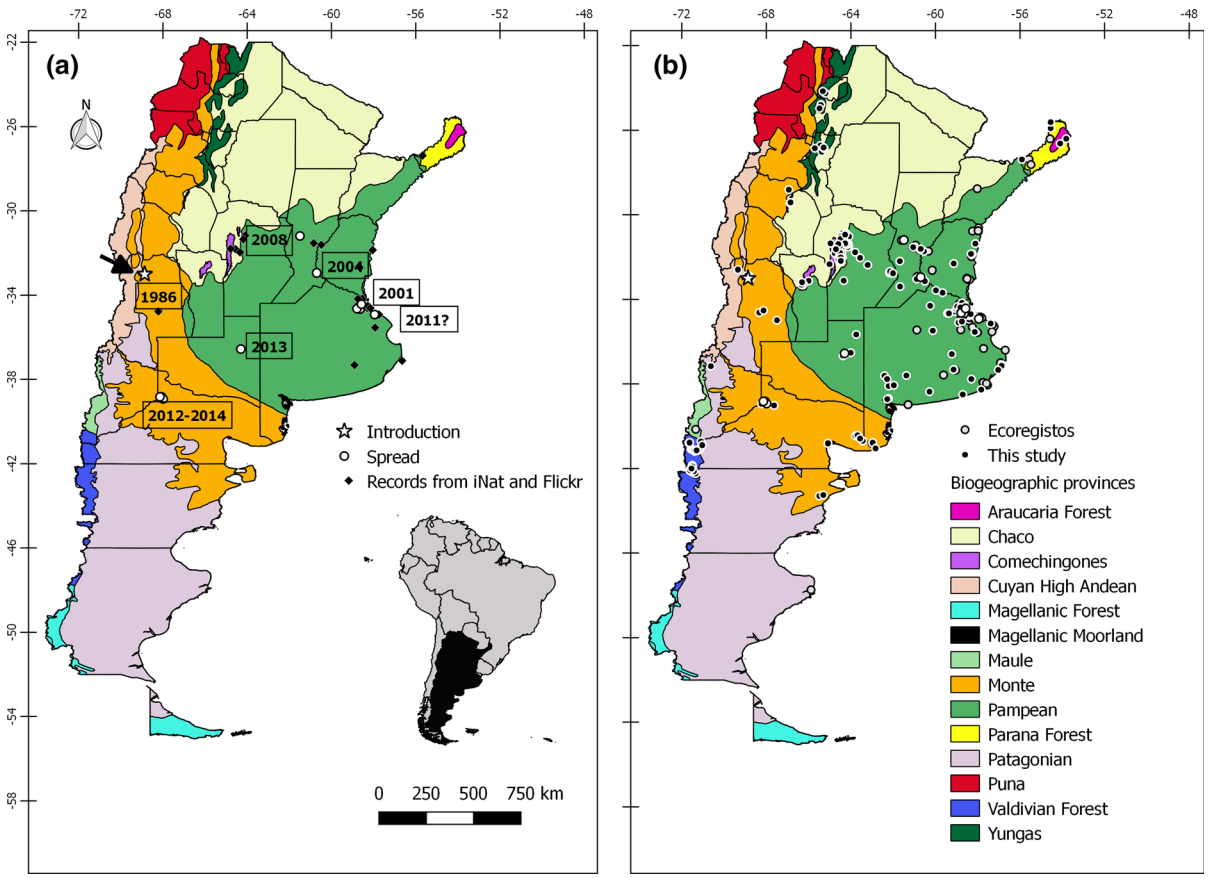

Fig. 1 Biogeographic regions in Argentina and the reported presence of *H. axyridis*: **a** before June 2018, and **b** after this study. **a** The arrow indicates the point of introduction and numbers in boxes indicate the year of the first reported establishment taken from literature (it does not include the year of pictures from iNaturalist and Flickr)

Methods

To gather citizen science records we developed a website (https://sites.google.com/a/comahue-conicet.gob.ar/vam) with information about the species and how to identify it, and we offered different ways for reporting data: (1) an iNaturalist project (https://www.inaturalist.org/projects/vaquita-asiatica-multicolor); (2) a Google form; and (3) an institutional email. In early June 2018 we widely promoted our project by sending more than 100 emails with a brief description and the link to the website to people from universities, scientific institutes, and scientific societies in Argentina, and we specifically asked them to widely disseminate the information to all their community members (not only within academia). We initially encouraged the use of iNaturalist in order to have open and georeferenced data. In December 2018 we reinforced the survey creating a flyer with summary information of the project which we disseminated on Facebook, Instagram and Twitter, and we added two additional ways of reporting records: (4) a WhatsApp number; and (5) a Facebook page (https://www.facebook.com/vaquita.asiaticamulticolor); also we circulated new e-mails to Institutions and scientists targeting regions lacking records. In addition, we received records and specimens from colleagues and other acquaintances, which we classified as "Other Methods".

We asked citizens to report the date and location of the sighting (as accurately as possible) and to send a picture in any life stage (larva, pupa or adult). For records lacking geographic coordinates, we approximated them by using Google Maps searching for the address, city, or locality name. We used the pictures to verify the species identity. When it was not possible to

confirm the identification, we asked the citizens to send a new picture, if possible. Only records with verified pictures were included in our database. We used QGIS 2.18 (Team, QGIS Development) and R 3.4.4 (R Core Team 2018) to analyse data.

Results and discussion

From June 2018 to July 2019 we received 370 records from 275 citizens. We also included in our database 17 records from eight citizens uploaded to iNaturalist previous to the promotion of our project, totalizing 387 records and 279 citizens. Pictures allowed us to verify 93% of submitted records (N = 361) to be *H. axyridis*. Seventy-eight per cent of these records (N = 283) were geo-referenced by the citizens (59%) or were sent with precise addresses (19%) allowing us to add accurate geo-references. Geographical coordinates of the remaining records were approximated by $\leq$ 10 km^2 (11%), between 10 to 50 km^2 (5.5%), and $>$ 50 km^2 (5.5%) depending on the information sent about the locality of the record. Additionally, one citizen alerted us to the records of *H. axyridis* in Ecoregistros (http://www.ecoregistros.org), an Argentinean naturalists website, from which we got 182 additional records from 2007 to 2019, leading to a total of 543 records of the species in Argentina (Fig. 1b; Online Resource 2, Table 2b).

Preferred ways of sending records

Citizens sent records using all the proposed methods. Most of the validated records came from iNaturalist (N = 152) and WhatsApp (N = 86), followed by email (N = 45), and Facebook (N = 27), while Google Forms and Other Methods contributed less than 10% of the records (N = 16 and N = 18, respectively). When we took into account the total number of days each method was available, the order of email and Facebook were slightly reverted. In addition, iNaturalist and WhatsApp showed a similar frequency of use (Fig. 2), indicating that both methods are good candidates for future citizen science projects within Argentina. The number of citizens was similar between iNaturalist (N = 89) and WhatsApp (N = 84), but iNaturalist users tended to send more than one record (Fig. 2). Before our project, there were only 17 records of *H. axyridis* in Argentina in the

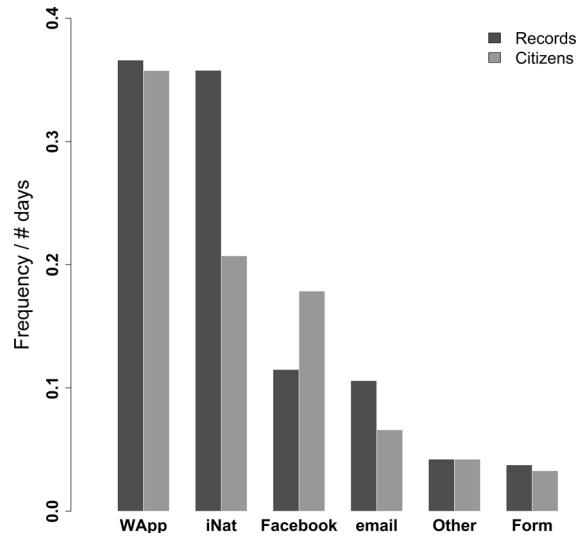

Fig. 2 Number of records received (dark grey) and number of citizens reporting records (light grey) by way of reporting. These numbers were divided by the number of days each method was active (N = 425 days for iNaturalist, Email, Google Form and Other methods, and N = 235 days for WhatsApp and Facebook)

iNaturalist website, which came from eight users. By the end of July 2019, the number of users was 93, and $\sim$ 70% of them created their profiles after the beginning of our project. It is reasonable to think that at least some of these citizens registered because of our request and thus, our project might also be promoting the use of iNaturalist in Argentina.

Encouraging the use of iNaturalist and other citizen science platforms is particularly relevant because it provides valuable open data which can be easily used by the scientific community worldwide beyond the objective of a particular project. Citizen science open data platforms have shown to be a valuable source of records of many types of organisms for many fields of research. For instance, data available in these platforms have been used to generate models to understand current and future distribution and status of plants and animals (Chardon et al. 2015; Outhwaite et al. 2019), to analyse phenotypic variation of insect species (Drury et al. 2019), and to bolster museum collections data of native and invasive reptiles and amphibians particularly from urban and suburban areas (Spear et al. 2017) among many other cases.

Distribution of *H. axyridis* in Argentina

Taking this project and Ecoregistros records together, *H. axyridis* in Argentina seems to extend from at least 24° to 43° S and from 71° 30′ to 54° W, having arrived in ten biogeographical regions (Fig. 1b; Online Resource 3). The southern limit is mismatched with climatic predictions (Koch et al. 2006; Poutsma et al. 2007), but is climatically similar to some regions from which reports were generated in Chile (Alaniz et al. 2018; Grez et al. 2016) and to high latitudes in the United Kingdom, where the species shows limited abundance in northern England and Scotland (Purse et al. 2015; Roy et al. 2016). This high latitude limit in the invaded region has been related to the combination of low temperatures and high precipitation (Alaniz et al. 2018; Roy et al. 2016) and to the low density of urban areas (Purse et al. 2015). In our study, most of the southern records were reported in the Valdivian Forest, close to the Andes, where precipitation is high (> 2000 mm/year) compared to the east of the country (ca. 300 mm/year) (Barros et al. 1983). Although precipitation is high in the Valdivian Forest, these records came mostly from or close to urban areas which might be promoting the invasion of the species. Human-altered habitats, like towns and cities, promote biological invasions (Hufbauer et al. 2012) and have been mentioned as a factor shaping the invasion of *H. axyridis* in particular (Grez et al. 2016; Purse et al. 2015; Veran et al. 2016). The low population density in the Patagonian province and the decrease in temperature toward the south might explain at least in part the low abundance of records there.

According to the number of records and the comments from citizens, the establishment of the species in the Valdivian Forest seems to be very recent (2017–2018; Online Resource 3). The citizens reporting records in this region claim the species had not been seen before the summer of 2017, and most of them reported an extraordinary abundance of overwintering individuals inside houses in the autumn 2019. This region has connections through road traffic with neighbouring localities in Chile where the species was reported in 2015 (Grez et al. 2016), thus one possibility is that the invasion in this region came from Chile. Supporting this idea, a citizen who frequently travels between Osorno (Chile) and Bariloche (Argentina) reported that she used to see this ladybird among her belongings when she unpacked in Argentina. Future genetic analysis might help track the route of the invasion in the Valdivian Forest and the Patagonian provinces.

In Ecoregistros, we found an extreme record at ~ 48° S, 66° W in the west of the Patagonian province sent in 2017 (Puerto Deseado; Fig. 1b). We contacted the user who sent this record and it seems the species is not established in this locality as it has not been seen again. Our project began almost 20 years after the first signs of invasion of *H. axyridis* in Argentina, and thus our citizen science records are not suitable to track its invasion across the country as has been done in other countries (e.g. Grez et al. 2016; Purse et al. 2015; Veran et al. 2016). Nonetheless, the recent invasion in the Valdivian Forest and the presence of the species in some localities in the adjacent Patagonian province indicate that our study is timely for monitoring the expansion and assessing the impacts of *H. axyridis* in one of the most austral regions of the world.

Our study expands the range of *H. axyridis* ~ 600 km further north than in Chile where the species seems to be restricted due to the presence of the Atacama Desert (Alaniz et al. 2018; Grez et al. 2016). Nevertheless, our records in the north correspond to a small region of subtropical forests in the East (Paraná Forest and Araucaria Forest) and West (Yungas) of Argentina, confirming the habitat matching predictions for this biome (Koch et al. 2006). Contrary to climatic matching predictions (Koch et al. 2006; Poutsma et al. 2007), the distribution shows a large gap in most of northern Argentina in the warm, arid/semi-arid Chaco, and in the arid Puna (despite having reinforced the survey in these regions). Although the absence of records does not necessarily mean the absence of the species, *H. axyridis* is rarely found in arid and warm regions of the world (Grez et al. 2016; Roy et al. 2016). It should be noted that we also received records of the species in several scattered locations in the Monte (annual precipitation: 80–250 mm, mean annual temperature: 13–17.5 °C; Cabrera 1971), which is within the Arid Diagonal of South America. However, here again, the records came mostly from urban areas or from irrigated and/or cultivated zones which are known to promote biological invasions (Hufbauer et al. 2012) and might be facilitating the presence of the species.

The most populated area of the country was also the one with the highest number of records of *H. axyridis*

(Pampean region; Online Resource 3). The Pampas are mainly warm temperate grasslands (mean annual temperature 13–17 °C; Cabrera 1971) with precipitation throughout the year (annual precipitation: 600–1100 mm; Cabrera 1971) that represents suitable climatic conditions for the establishment of *H. axyridis* (Koch et al. 2006; Poutsma et al. 2007). Also this region concentrates more than 70% of the cultivated areas in Argentina (INTA, National Agricultural Technology Institute). The high number of records in this area might be an artefact of our sampling method as in citizen science there is bias in the number of records towards highly populated areas (Dickinson et al. 2010). This might be the case, but the reported presence of the species since 2001 (Saini 2004), the highly invasive behaviour of *H. axyridis* (Roy and Wajnberg 2008), the wide distribution of records in this area, and the climatic suitability of this region (Koch et al. 2006; Poutsma et al. 2007), reasonably suggest that the species is widely established in the Pampas.

Citizen science as a powerful tool for the assessment of invasive species in large countries

Citizen science has been criticized because of lack of accuracy of the data and the non-standardized sampling effort (Dickinson et al. 2010). Nevertheless, this and other studies (e.g. Giovos et al. 2019; Grez et al. 2016; Hobson et al. 2017) demonstrate that it is a valuable tool for the assessment of invasive alien species over large spatial areas. The accuracy of identification was high in our system (93% of the pictures sent by citizens were verified to be *H. axyridis*), but we are aware that our records might be biased to urban areas, and are not exhaustive. Nevertheless, the records presented in this work allow us to have a first approximation of the state of invasion by *H. axyridis* in Argentina, providing a baseline for future studies on its requirements and impacts, and call for urgent national initiatives in the conservation of native ladybirds and other beneficial insects.

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