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The Outbreak of Harlequin Ladybird *Harmonia axyridis* (Pallas, 1773) (Coleoptera, Coccinellidae) in the Caucasus and Possible Sources of Invasion

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Abstract—Recently, the invasive harlequin ladybird (*Harmonia axyridis*), which has been speading rapidly throughout the world, has naturalized in the Caucasus. According to our data, the range of its outbreak covers the Black Sea coast of Krasnodar krai and part of the Abkhazian coast and also the southern and northern foothills of the Greater Caucasus. Both light (form *succinea*) and dark (form *spectabilis*) specimens are detected to the north of the mountain ridge, but there were no dark specimens among 220 beetles collected to the south of the mountain ridge. The drastic difference between populations indicates their different origin. Probably, the Transcaucasian population of beetles appeared as a result of their mass release in Georgia in the 1980s, and the Caucasian population appeared as a result of later releases of beetles in Krasnodar krai or of spontaneous expansion of the European range. The introduction of a new alien predator can affect the state of the Caucasian entomofauna. Harlequin ladybirds pose a threat to local populations of ladybirds as well as to butterflies which develop on leaves. In addition, *H. axyridis* can cause injury to fruits and grapes, posing a threat to fruit and wine production.

Keywords: *Harmonia axyridis*, harlequin ladybird, Coleoptera, Coccinellidae, pest, invasive species, Caucasus

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INTRODUCTION

The Asian lady beetle or the harlequin ladybird (*Harmonia axyridis* (Pallas, 1773)) is considered to be one of the world's most invasive beetles. The outbreak of *H. axyridis* in Europe and America caused severe negative impacts in those regions. The harlequin ladybird is a serious pest of fruit and wine production because the beetles feed on ripe fruit and grape berries (Koch and Galvan, 2008). When ladybirds are inadvertently processed along with grapes, their noxious odor can taint the flavor of wine. In some regions, the species became dominant and has a negative impact on local ladybirds and other insects (Roy et al., 2012). In addition, ladybirds can cause problems for humans since they aggregate in buildings when seeking winter hibernation sites. Bites of ladybirds cause irritation and inflammation the skin like the bites of mosquitoes (Ramsey and Losey, 2012). The beetles emit an acrid odor and can stain walls and furniture with their secretions and cause allergic reactions such as allergic rhinitis, hives, and asthma (Goetz, 2009).

The ladybird *H. axyridis* is native to East Asia from Altai krai to Japan (Poutsma et al., 2008). From 1916 until recent times, these very voracious and fertile ladybirds were bred and released into crop fields for the biological control of pest insects such as trips, whiteflies, and aphids. But their naturalization did not occur (Kuznetsov, 1993). The first naturalized populations were detected in the United States in 1988. Since that time, the harlequin ladybird has spread rapidly across different countries and continents. Over a 25-year period, *H. axyridis* has naturalized in at least 39 countries of Europe, Africa, and North and South America (Brown et al., 2011; Zakharov et al., 2011).

In the 1990s, findings of *H. axyridis* were recorded in France, Greece, Germany, Belgium, and the Netherlands, and since 2002 the species has started its "triumphal" spreading in Europe (Brown et al., 2011). Annual publications report on colonization of new countries by the harlequin ladybird. Three years ago, the range of the invasive harlequin ladybird reached the western borders of Russia. In 2010, its populations were recorded in Kaliningrad oblast (Zakharov et al., 2011). In 2012, solitary specimens of *H. axyridis* were recorded in Belgorod and Lipetsk oblasts (Orlova-Bienkowskaja, 2013; Ukrainsky and Orlova-Bienkowskaja, in press).

Table 1. Some releases of *Harmonia axyridis* in the Caucasus

Location	Decimal coordinates	Year of release	Source of information
Georgia, Adzharia, Batumi	41.57, 41.67	1982–1988	(Kuznetsov, 1988, 1993)
Georgia, Mtskheta region, Armazi Canyon	41.83, 44.69	1982–1988	(Kuznetsov, 1988, 1993)
Krasnodar krai, Crimean region, Novokrymsky	44.93, 37.79	2009, 2010	(Bugaeva et al., 2011)

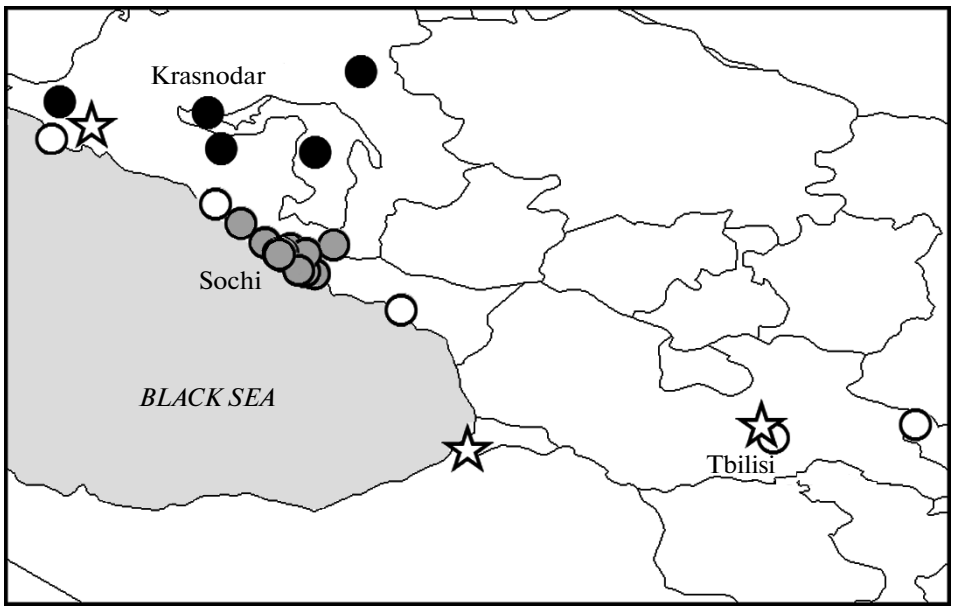
From 2002 to 2011, solitary specimens of *H. axyridis* were recorded in the Caucasus: in eastern Georgia in 2002 (Merkviladze and Kvavadze, 2002), on the Black Sea coast of Abkhazia in 2005 (Korotyaev, in press), in Adygei in 2006 (Ukrainsky and Shapovalov, 2010), and on the Black Sea coast of Krasnodar krai in 2011 (Ukrainsky, 2013). However, these solitary findings did not indicate the species naturalization. Harlequin ladybirds were released in mass in the Caucasus in different periods (Belyakova and Polikarpova, 2012), so the detected specimens could be dispersed laboratory insects.

In June 2012, schoolboy Timofei Mogilevich found a breeding site of *H. axyridis* near the settlement of Loo (Krasnodar krai, urban district of Sochi) and published the information about the finding on the site of the Zoological Institute, Russian Academy of Sciences (Mogilevich, 2012). The correctness of identification was examined by A.S. Ukrainsky, an expert in Coccinellidae. Breeding sites of harlequin ladybird were found in Sochi and near the settlement of Lazarevskoye in September 2012 (Belyakova and Polikarpova, 2012).

In April–May 2013, samplings of beetles were conducted in the vicinities of 12 settlements of Krasnodar krai, Adygei, and Abkhazia. Harlequin ladybirds were found everywhere and it was the most mass species of ladybirds. Comprehensive summaries of our and published data make it possible to conclude that the range of distribution of *H. axyridis* in the North Caucasus covers a vast territory and is not restricted to particular sites.

MASS RELEASES OF *H. axyridis* IN THE CAUCASUS

From the 1930s to the present, harlequin ladybirds have been released in the Caucasus for the biological control of aphids and other pests (Belyakova and Polikarpova, 2012). An attempt to naturalize the spe-



Sites of records and mass releases of *H. axyridis* in the Caucasus. Asterisks denote sites of some intentional releases of *H. axyridis* in nature. Black circles denote sites where the form *spectabilis* is present (dark-colored imagoes) (Table 2). Gray circles denote sites where the form *spectabilis* is absent (Table 3). White circles denote sites where the forms *spectabilis* was also not found, but the small volume of materials does not make it possible to reach a conclusion about its absence (Table 4).

Table 2. Locations of *H. axyridis* where the form *spectabilis* was recorded

Location	Number of larvae and pupae	Number of imagoes	Number of imagoes of the form *spectabilis*	Decimal coordinates	Date	Source of information
Adygei, Rodnikovy	0	1	1	44.61, 40.09	June 29, 2006	(Ukrainsky and Shapovalov, 2010)
Krasnodar krai, Bolshoi Raznokol	0	1	1	45.14, 37.47	Apr. 30, 2012	(Korotyaev, in press)
Krasnodar krai, Kropotkin	0	26	7	45.44, 40.56	Apr. 6, 2013	(Korotyaev, in press)
Krasnodar krai, Goryachiy Klyuch	8	5	1	44.65, 39.13	May 12, 2013	Our collections
Krasnodar krai, Krasnodar, Lakes Pokrovskiye	0	132	24	45.03, 38.99	June 14, 2013	Our collections
Adygei, settlement of Novyi	0	42	8	45.01, 38.98	June 14, 2013	Our collections

cies in Georgia was made from 1982 to 1988. More than 100000 imagoes of *H. axyridis* were brought from Primorsky krai and Sakhalin. But later, naturalized populations were not detected (Kuznetsov, 1993). The last mass releases of *H. axyridis* were in 2009 and 2010 (Bugaeva et al., 2011).

RESULTS

The information about our findings of *H. axyridis* from April 30 to June 14, 2013, and findings according to the published data is presented in Tables 2–4.

In 2012, breeding sites of harlequin ladybird were detected only in settlements on the Black Sea coast (Mogilevich, 2012; Belyakova and Polikarpova, 2012). According to our data, harlequin ladybirds occur in mass not only on the coast but also in mountain forests at the distance of 40 km from the sea. Both imagoes and larvae of harlequin ladybird are found in mountains. This testifies to a complete life cycle of the species.

Harlequin ladybird dominated by abundance among other species of ladybirds in all studied biotopes: in bushes of the river floodplain, in a broad-leaved mountain forest, and in urban green plantations. In some sites, for example, in the microdistrict Bytkha of Sochi, grass, soil, and walls of houses were crawling with larvae of *H. axyridis*. Their density exceeded several hundred per square meter.

In the North Caucasus, the laboratory breeding of *H. axyridis* for release in greenhouses is no longer reasonable. Imagoes and larvae can be collected in nature.

It should be noted that, for a 13-day sampling period, we found only four specimens of *Coccinella septempuctata* (Linnaeus, 1758) and three specimens of *Harmonia quadripunctata* (Pontoppidan, 1763). We can suggest that the introduction of the alien harlequin ladybird caused a sharp decrease in the abundance of local ladybirds, as happened in some regions of Western Europe (Roy et al., 2012). This hypothesis requires quantitative studies and monitoring of ladybirds in different seasons.

THE RATIO OF COLOR FORMS AND POSSIBLE SOURCES OF INVASION

About 220 specimens of *H. axyridis* imagoes were collected to the south of the Greater Caucasus in different sites and in different periods. However, no dark-colored specimens (form *spectabilis*) were recorded. But among 207 specimens collected at the northern macroslope of the Greater Caucasus and in plain regions of Krasnodar krai, 42 specimens were dark in color. The inheritance of elytral color patterns is monogenic and controlled by a multiallelic locus (Zakharov and Blekhman, 2001). A sharp difference in phenotypic ratio indicates differences in the genetic structure of populations. This can be explained by the fact that northern and southern populations of harlequin ladybird in the Caucasus originated from spontaneous introductions from the native range. The absence of the form *spectabilis* points to the founder

Table 3. Locations where many imagoes of *H. axyridis* were collected, but specimens of the form *spectabilis* were not detected

Location	Number of larvae and pupae	Number of imagoes	Decimal coordinates	Date	Source of information
Krasnodar krai, Loo	More than 20	More than 20	43.70, 39.59	June 9–July 13, 2012	(Mogilevich, 2012)
Krasnodar krai, Lazarevskoye	39	8	43.90, 39.34	Sept. 27, Oct. 1, 2012	(Belyakova and Polikarpova, 2012)
Krasnodar krai, Sochi	39	3	43.70, 39.59	Sept. 28, 2012	(Belyakova and Polikarpova, 2012)
	12	7	43.59, 39.72	Sept. 30, 2012	(Belyakova and Polikarpova, 2012)
	0	2	43.57, 39.75	Apr. 30, 2013	Our collections
	More than 100	7	43.56, 39.76	May 8, 2013	Our collections
Krasnodar krai, Razdol'noye	More than 100	More than 70	43.59, 39.77	May 1, 2013	Our collections
Krasnodar krai, Abazinka	33	6	43.59, 39.82	May 6, 2013	Our collections
Krasnodar krai, Semenovka	10	3	43.64, 39.85	May 4, 2013	Our collections
Krasnodar krai, Adler	0	More than 20	43.42, 39.93	Nov. 2012	A.A. Mokhrin, private communication
	0	24	43.42, 39.93	May 11, 2013	Our collections
Krasnodar, Veseloe	More than 100	24	43.40, 39.99	May 11, 2013	Our collections
	More than 20	8		May 2, 2013	Our collections
Krasnodar krai, Monastery	0	40	43.59, 40.01	May 3, 2013	Our collections
Krasnodar krai, Roza-Khutor	0	11	43.68, 40.29	May 3, 2013	Our collections
Abkhazia, Tsandrypsh	More than 100	4	43.38, 40.09	May 9, 2013	Our collections

effect; i.e., the southern population originates from a small number of only light-colored specimens.

Probably, naturalization of *H. axyridis* in the Transcaucasian region was the result of its releases in Georgia in the 1980s. The first findings of *H. axyridis* in the Caucasus were recorded in Georgia (Merkviladze and Kvavadze, 2002). At the beginning of the 2000s, the penetration of the species from Europe was hardly possible because the eastern boundary of the European invasive range was located much further to the west, in Germany (Brown et al., 2011).

But how can we explain the fact that specimens of harlequin ladybird were not recorded in the wild from its release in the 1980s to 2002? First, monitoring of entomofauna in the Caucasian region was not conducted regularly because of the difficult economic and political situation in the 1990s. Second, the population could have been local and not numerous. A temporal gap between invasion and the peak in abundance is typical of many alien insect species (Maslyakov and Izhevskii, 2011).

Harlequin ladybirds could have propagated to the north from the Greater Caucasian watershed as the

Table 4. Locations where the form *spectabilis* was not found in populations of *H. axyridis*, but the small volume of material does not make it possible to reach a reliable conclusion about its absence

Location	Number of larvae and pupae	Number of imagoes	Decimal coordinates	Date	Source of information
Georgia, Kakheti, Lagodekhi National Park	?	?	41.82, 46.27	Before 2002	(Merkviladze and Kvavadze, 2002)
Abkhazia, Sukhumi	0	1	43.01, 40.99	Dec. 2005	(Korotyaev, in press)
Krasnodar krai, Bolshoi Utrish	0	1	44.76, 37.39	Aug. 15–25, 2011	(Ukrainsky, 2013)
Georgia, Tbilisi, Narikala fortress	?	?	41.69, 44.81	June 16, 2012	(Schlüter, 2012) information placed on the Internet by an amateur naturalist and not checked by experts
Krasnodar krai, Tuapse	2	1	44.10, 39.08	May 7, 2013	Our collections

result of later releases in Krasnodar krai or spontaneous expansion of the European range.

POSSIBLE CONSEQUENCES OF MASS REPRODUCTION OF HARLEQUIN LADYBIRD IN THE CAUCASUS

Earlier, it was proposed to include *H. axyridis* in the list of quarantine species (Orlova-Bienkowskaja, 2013). However, now, this proposal is no longer relevant because the process of spreading and reproduction of *H. axyridis* has become uncontrollable in the Caucasian region and in many regions of the world. Measures aimed at the restriction of the abundance of invasive harlequin ladybird or prevention of further expansion of its range have not been developed. We can only monitor the effect that the new mass species will exert on native communities and human activity. The introduction of *H. axyridis* can cause both positive and negative consequences. On one hand, harlequin ladybird can reduce the abundance of aphids in crop fields and urban green plantations. It is called "a six-legged alligator" because of its voracity. During its life, one specimen can consume up to 5000 aphids (Nedvěd et al., 2010). If the harm to crops by aphids decreases, the amount of pesticides used for plant protection can also decrease, which will have a favorable effect on the environment.

On the other hand, harlequin ladybird is a pest both to harmful and harmless insects not only in agrocenoses but also in natural communities. The mass development of a new plurivorous dominant predator affects the structure of local entonofauna. First of all, it poses a serious threat to all Caucasian Coccinellidae. It is known that the introduction of harlequin ladybird led to a sharp decrease in the abundance of native ladybirds and disappearance of some species (Roy et al., 2012). There are several reasons for replacement of native ladybirds by Asian ladybirds. First, because of high fecundity and voracity, harlequin ladybirds undermine the forage resources. Second, larvae of harlequin ladybirds feed on eggs and larvae of other ladybirds. Third, *H. axyridis* excretes noxious agents which prevent egg laying by other species (Pell et al., 2008).

H. axyridis is a pest not only to ladybirds but also to other arthropods. It devours psylla, ticks, Coccidae, larvae of leaf beetles and weevers, and caterpillars of butterflies (Koch, 2003). Mass development of harlequin ladybird can have a negative impact on populations of rare, endemic, and protected species of insects in the Sochi National Park, the Caucasian State Nature Reserve, and in the region. Caterpillars of butterflies on leaves are the most vulnerable by aggregations of ladybirds. In America, the invasive *H. axyridis* decreased the abundance of the butterfly *Danaus plexippus* (Linnaeus, 1785) (Koch and Galvan, 2008).

In its native range in East Asia, harlequin ladybird does not pose a threat to crops. However, in the invasive range in Europe and America, the species can cause serious damage to apples, pears, citrus plants, and grapes, posing threat to fruit and wine production (Branquart and Koch, 2010). Mass reproduction of harlequin ladybird is a concern of the Caucasian wine industry as it can taint the flavor of wine.

Finally, aggregations of harlequin ladybirds in buildings as occurs in many regions can make less comfortable the conditions of recreation and therapy in resorts of the North Caucasus (Koch and Galvan, 2008).

PROSPECTS OF STUDIES

Mass reproduction of harlequin ladybird in some regions of the North Caucasus indicates the probability of its range expansion in the south of Russia. It is necessary to study the fauna of Coleoptera in adjacent regions to determine the range boundaries. Harlequin ladybird can affect the structure of native communities, so the importance of monitoring of entomofauna in the Caucasian region increases. It is necessary to monitor the state of the local populations of ladybirds and butterflies.

At present, the region where forms *spectabilis* are detected is adjacent to the region where these forms are absent. Probably, we can expect hybridization of populations of different origin. The study of this process is of interest from the practical and theoretical point of view since it is known that crossing of unrelated populations of *H. axyridis* can result in appearance of large and more fecund specimens (Facon et al., 2011).

It is important to assess the economic effectiveness of the naturalization and to determine the ratio of profits and losses. Probably, this experience will make it possible to estimate the prospects of future use of biological methods for pest control.

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