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Insectum non grata: the harlequin ladybird, *Harmonia axyridis* (Pallas, 1773) (Coleoptera, Coccinellidae) in Turkey

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Abstract: The Harlequin Ladybird, *Harmonia axyridis* (Pallas, 1773), is native to Eastern Asia but it has been introduced to many countries in Africa, America, and Eurasia. In Turkey, *H. axyridis* is one of the most fast-spreading invasive alien species. Since the collection of the first specimens in 2010, *H. axyridis* spread almost all over the country. The species spreads fast in Turkey according to the new records, obtained originally from the field studies and the citizen science data. It was recorded for the first time from 19 of 81 Turkish provinces (Ankara, Antalya, Balıkesir, Bolu, Bursa, İstanbul, İzmir, Karaman, Kastamonu, Kırklareli, Kocaeli, Muğla, Rize, Samsun, Sinop, Tokat, Trabzon, Yalova, and Zonguldak) from Aegean, Central and Eastern Black Sea regions. We used the MaxEnt program to predict the current and future potential geographical distribution of this species in Turkey and its surrounding areas. Based on MaxEnt predictions, the majority of this region seems highly suitable for the species.

Key words: *Harmonia axyridis*, distribution, MaxEnt, citizen science, invasive species

1. Introduction

The Harlequin Ladybird, *Harmonia axyridis*, was originally described as *Coccinella axyridis* Pallas, 1773 (Coleoptera: Coccinellidae) and it is native to Eastern Asia (China, Japan, Korea, Mongolia, Eastern Russia, Central Siberia, Kazakhstan, Uzbekistan, Vietnam, and Taiwan). Since it is one of the best-known biological control agents to control aphids and scale insects, it is introduced to all continents except Antarctica, both intentionally and unintentionally. The species successfully distributes in Europe, South and North America, the Near East, Africa, and it has recently become one of the most invasive insect species, which tends to outcompete and feed on native ladybirds (Kuznetsov, 1997; Koch et al., 2006; Brown et al., 2011; Roy et al., 2016; Camacho-Cervantes et al., 2017; Biranvand et al., 2019).

There are two publications (Aysal and Kıvan, 2014; Bukejs and Telnov, 2015) for the first records of this species in Turkey. Aysal and Kıvan (2014) collected samples in 2011–2012 in Tekirdağ province, the European part of the country, and Bukejs and Telnov (2015) found a single specimen in Göreme (Nevşehir prov.) in July 2013. The priority suggests being the first report of *H. axyridis* for Turkey is Aysal and Kıvan (2014). The species were also reported from Çanakkale (Baştuğ and Kasap, 2015), Yozgat (Tiftikçi, 2017), Bartın (Toper Kaygın and Sobutay Kaptan, 2017), Düzce (Öztemiz and Yayla, 2018), Isparta (Oğuzoğlu and Avcı, 2019), Sakarya (Öztemiz and Keskin, 2019), and Ankara (Eşer, 2020). Additionally, Görür et al. (2015) mentioned it as the predator of *Cinara cedri* from Afyonkarahisar and Kütahya provinces. But they did not give locality for the ladybird.

H. axyridis is one of the ideal species for modeling studies. Poutsma et al. (2008) presented predictions for the potential geographical distribution of this species in the world, using the CLIMEX model. During this period, the presence of this species in Turkey was not yet known. In the following years, no studies have been carried out in Turkey on the potential distribution of *H. axyridis*, by using modeling software.

On the other hand, the increasing usage of the Internet has led to the development of databases that nonscientists can also contribute to science. These are just two examples, namely the websites; DoğalHayat, related with the fauna and flora of Turkey, and international iNaturalist.

This paper aims to present the current distribution, future potential and suitable habitats of *H.axyridis*, which

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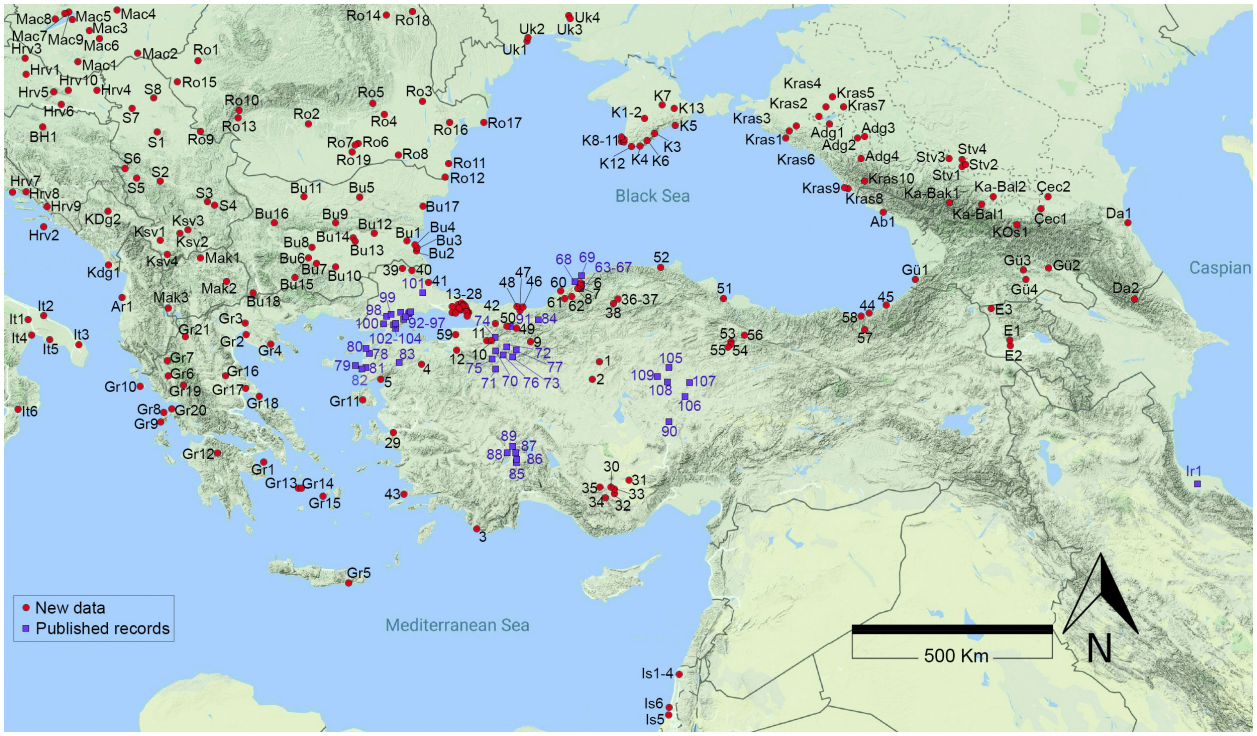

Figure 1. New and published records of *Harmonia axyridis* from Turkey and neighboring countries. The number of localities on the map explains in the text.

is one of the best known and most rapidly spreading invasive alien species in Turkey. Also, this paper is an example of the significance of the data obtained by Citizen Science sources.

2. Materials and methods

Besides original data, the records from two biota databases were used for this study. There are 61 records of *H. axyridis* in the website DoğalHayat[1] from Turkey by July 1st, 2020. Some of them are from the same locality and the same date and the remaining records are from 41 different localities. The website iNaturalist[2] gives 16 records of the species from Turkey. The latter site also reported 240 records from 168 places close to Turkey, namely the Balkans, the Caucasus, Israel, and Ukraine. These were evaluated in this study and listed as the supplement materials. All known records of *H. axyridis* from Turkey and neighboring areas were summarized in the map (Figure1).

2.1. Identification

The body of the Harlequin Ladybird is oval in shape and strongly convex. Its pronotum patterns show polymorphism. The pronotum is usually white with four to five black that tends to form an M formation. In some individuals, it is white in lateral margins and its center has a large trapezoid black patch. The sexes are similar. The main difference between male and female individuals is on the last ventral segment of the abdomen.

This polymorphic species has morphological variations in large scale and various color forms. Three main color forms, forma *conspicua*, f. *spectabilis*, and f. *succinea* are more common, and it is possible to see the records of these forms in Turkey. Examples of this polymorphism are illustrated in Figure 2. The common form, forma *succinea* has a cream color, orange, reddish-brown, or red background color of the elytra with 0–22 black markings. The forma *conspicua* and forma *spectabilis* have uniformly black elytra with two or four yellow or reddish spots, respectively.

2.2. Input data

A total of 125 occurrence data were obtained from literature surveys and field studies in the years between 2010 and 2020. To remove duplicates and avoid sampling bias, the records were rarefied spatially at 50 km intervals by using SDMtoolbox (Brown, 2014) in ArcGIS version 10.6.1 (ESRI, 2020)[3]. This process provided 50 occurrence records for ecological niche modeling.

[1] DoğalHayat (2020). Website https://dogalhayat.org/ [accessed 20 July 2020].

[2] iNaturalist (2020). Website https://www.inaturalist.org/taxa/48484-Harmonia-axyridis/ [accessed 20 July 2020].

[3] ESRI (2020). Website https://www.esri.com/ [accessed 01 August 2020].

Figure 2. Larva (a) and adults (b–i) of *Harmonia axyridis* (Pallas, 1773). Comparison of elytral colour patterns in adults: c and f. forma *succinea* (Bursa: Ürünlü, 10.VI.2015: Bülent Biçici and İstanbul: Beykoz, 26.VIII.2016: Özgür Koçak), e. forma *conspicua* (Zonguldak, 19.XI.2018: Erdinç Asar), g. forma *spectabilis* (Karaman: Kazımkarabekir, 30.VI.2017: Özgür Koçak).

Nineteen bioclimatic variables were downloaded from WorldClim database version 2.1 (Fick et al., 2017) at a spatial resolution of 2.5' (~4.63 km at the equator). For future projections (for the period 2021–2040) CNRM-CM6-1 model for two SSPs (SSP126 and SSP585), which represents a gradual decline in CO_2 emission and substantially higher CO_2 respectively, were considered at a resolution of 2.5' (CarbonBrief, 2020)[4].

2.3. Ecological niche models

All layers for each projection were clipped using SDMtoolbox, and each projection for the ecological niche models were performed between 24° and 49°E and 30° and 44°N, which was also the calibration area. To reduce multicollinearity, highly correlated climatic variables were removed under allowed the 0.7 maximum correlation value, which left seven variables: Bio3, Bio6, Bio7, Bio8, Bio15, Bio16, Bio18.

[4] CarbonBrief (2020). Website https://www.carbonbrief.org/ [accessed 01 August 2020].

For the model calibration, Cobos et al. (2019) were followed, and the kuenm R package was used. Calibration models were created with multiple combinations of 4 regularization multipliers (0.1, 0.5, 1, and 2), 29 feature class combinations, and 3 distinct sets of environmental predictors. Model performance was evaluated based on statistical significance (Partial_ROC), omission rates (OR), and the Akaike information criterion corrected for small sample sizes (AICc) (Figure 3). Partial ROC (Peterson et al., 2008) and omission rates were evaluated based on models created with training occurrences, whereas AICc values were calculated for models created with the full set of occurrences (Warren and Seifert, 2011). The best model was selected according to distinct, user-set criteria (Table 1), where the regularization multiplier is 2, the feature class is T (threshold), and the set of environmental variables which contains Bio6, Bio7, Bio15, and Bio18.

Finally, MaxEnt version 3.4.1 (Philips and Dudik, 2008) was run for current and future projections under the settings for the selected parameterization for the best model where default and bootstrap were the replicated run type. Each model was replicated ten times. The raster calculation was implemented in ArcGIS version 10.6.1.

3. Results

New Records ([DH] denotes records from Doğalhayat[1] and [iNat] shows ones from iNaturalist[2] and * shows other unpublished data)**:** ***Ankara*****:** "Ankara" [1], 31.V.2020, rec. "kritis"[iNat];Haymana, İkizce [2], Esenbel Konutları, 07.VII.2020, Fatih Akkoç [iNat]. – ***Antalya*****:** Kaş, Kalkan [3], 08.IX.2016, Oktay Kuşoğlu[DH]. – ***Balıkesir*****:** (central=Altıeylül) [4], 04.XI.2018, Mueclainh [iNat]; Akçay [5], 25.VII.2017, Merav Vonshak [iNat].– ***Bartın*****:** Bartın (central) [6], 11.III.2017, Hasan Yaşayacak[DH]; Kutlubeyyazıcılar Vil. [7], 01.XII.2016, [DH]; Tuzcular Vil. [8], 16.V.2018, Furkan Eren[DH]. – ***Bolu*****:** Göynük, Çaylakköy Vil. [9], 24.V.2017, M. Coşkun Sancar[DH]. – ***Bursa*****:** İznik, Çamoluk Vil. [10], 10.III.2016, M. Coşkun Sancar[DH]; İznik, Dırazali Vil. [11], 09.X. 2015, M. Coşkun Sancar[DH]; Nilüfer, Ürünlü [12], 10.VI.2015 & 19.V.2016, Bülent

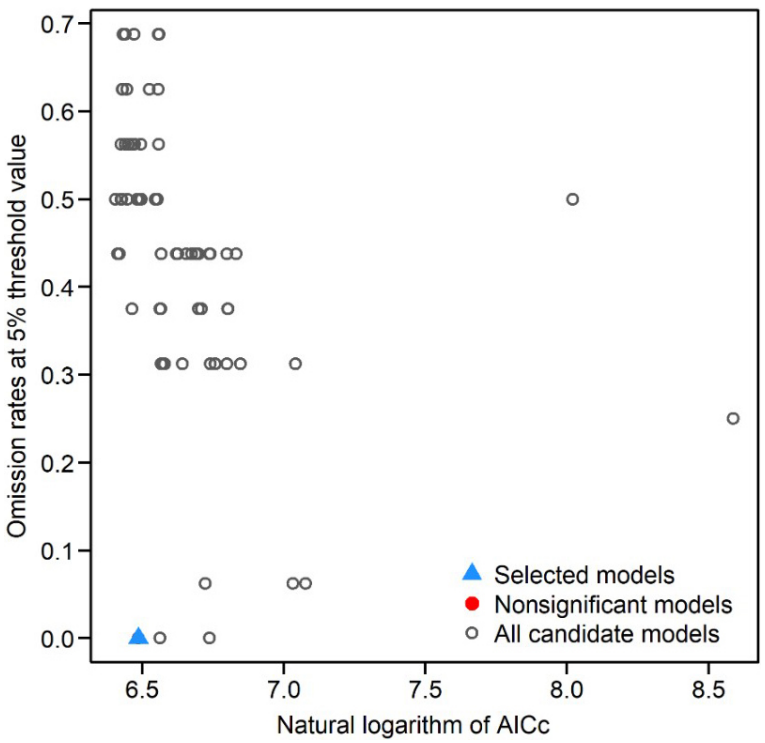

Figure 3. Distribution of all models, nonstatistically significant models, and selected models in terms of the user's predefined criteria.

Table 1. Performance statistics for the best models selected on the user's predefined criteria.

Model	*Mean_AUC_ratio*	*Partial_ROC*	*Omission_rate_at_5%*	*AICc*	*Delta_AICc*	*W_AICc*	*Num_parameters*
M_2_F_t_Set2	1	0	0	656.193	0	1	10

Biçici[DH]. – ***İstanbul*:** "İstanbul" [Eyüp] [13], 19.XI.2019, Bahadır Bildiren[iNat];Beşiktaş, Arnavutköy [14], 29.IX.2019, Umut Güngör[DH]; Bakırköy [15] 20.IX.2016, Ali Şeker[DH]; ibid., Basınköy, Çekmece Yolu Str. 22-26 [16], 12.IX.2016, "ilo" [iNat]; Başakşehir, Şamlar [17], 07.VI.2014, Fikret Karacan[DH]; Beykoz [18], 26.VIII.2016, Özgür Koçak[DH]; Eyüp, Kemerburgaz [19], 05.XI.2010, Fikret Karacan[DH]; Kartal, Pamukkale Sok. [20], 01.VII.2020, "doruk912"[iNat]; Sancaktepe, Eyüp Sultan Mah., Semerkand [21], 24.V.2019, Tolga Coşkun [iNat]; Sarıyer, Darüşşafaka, Balabandere Str. [22], 13.IX.2019, "ubtaso" [iNat]; Sarıyer, Reşitpaşa Mah., İTÜ Ayazağa Campus [23], 30.V.2018, Burcu Deniz [iNat], ibid., 09.VI.2020, "ozgurek"[iNat]; Sarıyer, near Koç Üniv. W Campus [24], 02.VII.2020, Güray Dere[iNat]; Ümraniye, Çamlık Mah., near Şenol Güneş Avenue [25], 24.X.2014, 09.V.2015*, 14.V.2015*, 31.V.2015*, 14.XI.2015*, Niyazi Tosun[DH]; ibid., Madenler Mah., near Şile highway [26], 25.VIII.2014, Niyazi Tosun[DH]; ibid., Şerifali Mah. [27], 13.VI.2015, Niyazi Tosun*; ibid., Yenişehir Mah., near Soyak Sitesi [28], 15.IV.2015, Niyazi Tosun[DH].– ***İzmir*:** Karabağlar, Yeşilyurt [29], 08.XI.2015 & 25.X.2015, Betül Özlem Yurdakul[DH]. – ***Karaman*:** (centrum) [30], 02.XI.2010, Özgür Koçak[DH]; Ayrancı [31], 17.VI.2012, Özgür Koçak[DH]; Gökçe Vil. [32], 29.V.2019, Özgür Koçak*, ibid., 20.V.2020, Mehmet Güney[DH]; Dereköy [33],11. VII.2020, Mehmet Güney[DH]; Bucakkışla [34], 28.VII.2013, Özgür Koçak[DH]; ibid., 30.V.2020, Mehmet Güney[DH]; Kazımkarabekir, Hacıbaba Mountain [35], 07.IX.2015, 30.VI.2017, Özgür Koçak[DH]. – ***Kastamonu*:** Araç, Yeni Esenkent Sitesi [36], 15.IX.2014, 17.XI.2019*, Niyazi Tosun[DH]; Araç, Gemi Vil. [37], 16.VII.2016*, 02.VIII.2018*, Niyazi Tosun*; ibid., Yukarıoba Vil. [38], 01.VIII.2015, 10.VIII.2015, 20.VIII.2015, 22.VIII.2016*, 29.VII.2019*, Niyazi Tosun[DH]. – ***Kırklareli*:** Kırklareli (central), Dereköy [39], 30.V.2015, Özlem Yıldız[DH]; ibid., 30.V.2015, Ufuk Karaca[DH]; Demirköy, Gökyaka Vil., Karanlık Mah. [40], 20.VI.2019, Emirhan Yücel[iNat]; Vize, Kıyıköy [41], 05.XI.2019, Nizamettin Yavuz[DH]; – ***Kocaeli*:** İzmit [42], 12.VI.2015, İrfan İlker Özek[DH]– ***Muğla*:** Bodrum, Gümbet [43], 15.XII.2019, Tamsin Carlisle[iNat].– ***Rize*:** Derepazarı, Tersane ÇAYKUR [44], 27.VII.2020, Ahmet Karataş*; Pazar [*45*], 05.IV.2018, Halim Demircioğlu[DH]. – ***Sakarya*:** Karasu, Kuzuluk Mah. [46], 01.IX. 2015, 25.VII.2016, Furkan Eren; ibid., 10.VIII.2016, 14.X.2016, 17.VII.2017, Abdulkadir Eren[DH]; ibid., Tuzla Mah. [47], 31.VII.2016, 08.X.2016, 24.VI.2017, 25.VI.2017, Gökhan Eren[DH]; ibid., Acarlar Floodplain Forest [48], 24.V.2016, Niyazi Tosun*; Karapürçek, Teketaban Vil. [49], 12.VI.2020, Ali Yılmaz[iNat]; Sapanca [50], 19.X.2016, Tamsin Carlisle [iNat].– ***Samsun*:** İlkadım, Gençlik Parkı (near harbour) [51], 28.III.2016, Gökhan Eren[DH]. – ***Sinop*:** Ayancık [52], 05.VII.2016, Hasan Yaşayacak[DH]. – ***Tokat*:** Tokat (centrum) (650 m a.s.l.) [53], 09.VII.2017, 29.X.2017, 07.IV.2018, 22.IV.2018*, 17.VI.2018; ibid., Hasanbaba Hill, Gıjgıj [54], 750 m a.s.l., 19.V.2018*; ibid., Kızıliniş [55], 1200 m a.s.l., 20.V.2018*; Niksar, Dönekse Valley [56], 550 m a.s.l., 08.IV.2018*, Ömer Toraman[DH]. – ***Trabzon*:** Çaykara, Uzungöl [57], 25.VII.2020, Ahmet Karataş*; Sürmene, Çamburnu Port [58], 28.VIII.2018, Ahmet Karataş[DH]. – ***Yalova*:** Armutlu [59], 20.VI.2016, Ali Şeker[DH]. – ***Zonguldak*:** Zonguldak (central) [60], 12.VI.2016, 19.XI.2018, Erdinç Asar[DH]; Devrek, Kabaca [61], 28.X.2018, 17.VI.2020, Murat Yangın[DH]; Gökçebey, Bakacakkadı [62], 01.VI.2020, 16.VI.2020, Erdinç Asar[DH].

Published records: *Bartın*: Bartın (Centrum) [63], Bahçeşehir Koleji [64], Çağlayan [65], Ağdacı Vil. [66], Kutlubeydemirci Vil. [67], İnkum [68], Amasra [69] (Toper Kaygın and Sobutay Kaptan, 2017).– ***Bilecik*:** Bilecik (Central), Pelitözü [70]; Bozüyük, 1.6 km NW Çokçapınar [71]; Gölpazarı, 4.2 km SW Gölpazarı, Reşadiye Mah. [72]; İnhisar, Karaağaç Mah. [73]; Osmaneli, Sarıyazı [74]; Pazaryeri, Arapdede [75]; Söğüt, Küre [76]; Yenipazar, 2.5 km NW Yenipazar [77] (Biranvand et al., 2019). – ***Çanakkale*:** Çanakkale (Central) [78], Bozcaada [79], Eceabat [80], Ezine [81], Geyikli [82], Yenice [83] (Baştuğ and Kasap, 2015). – ***Düzce*:** Konuralp [84] (Öztemiz and Yayla, 2018). – ***Isparta*:** Isparta (central) [85]; SDÜ Campus [86]; Gönen [87]; Keçiborlu [88]; Uluborlu [89] (Oğuzoğlu and Avcı, 2019). – ***Nevşehir*:** Göreme [90] (Bukejs and Telnov, 2015). – ***Sakarya*:** Arifiye [91] (Öztemiz & Keskin, 2019). – ***Tekirdağ*:** Süleymanpaşa (centrum [92], Değirmenaltı [93], Ferhadanlı [94], Köseilyas [95], Mermer [96], Naip [97]), Malkara (Camiatik [98], Evrenbey [99], Yenidibek [100]), Saray (Küçükyoncalı [101]), Şarköy (Eriklice [102], İshaklı [103], Palamut Vil. [104]) (Aysal & Kıvan, 2014). – ***Yozgat*:** Yozgat (central) *[105],* Boğazlıyan [106], Sarıkaya [107], Şefaatli [108], Yerköy[109] (Tiftikçi 2017).

Additionally, Görür et al. (2015) mentioned presence of *H. axyridis* from Aslanapa (Kütahya prov.), Büyükkalecik/ Yüzbaşı Agâh Efendi Şehitliği and Kocatepe/Büyükkalecik (Afyonkarahisar prov.), and also Hasankadı and Gecen villages (Bartın prov.), where *Cinara cedri* Mimeur 1936 (Hemiptera: Aphididae) records were taken from all of these places. But it is questionable that *H. axyridis* was found from all of them or some of them. Therefore, these localities were given with question mark on the map (Figure 1).

The current and future ENM prediction results were given in Figure 4. The ecological niche modeling results provided a high area under curve (AUC) values for the training data, indicating that all models had a strong predictive ability (mean AUC = 0.895, SD = 0.016). The response curves showed that Bio6 (min temperature of coldest month), Bio7 (temperature annual range), Bio15 (precipitation seasonality), and Bio18 (precipitation of

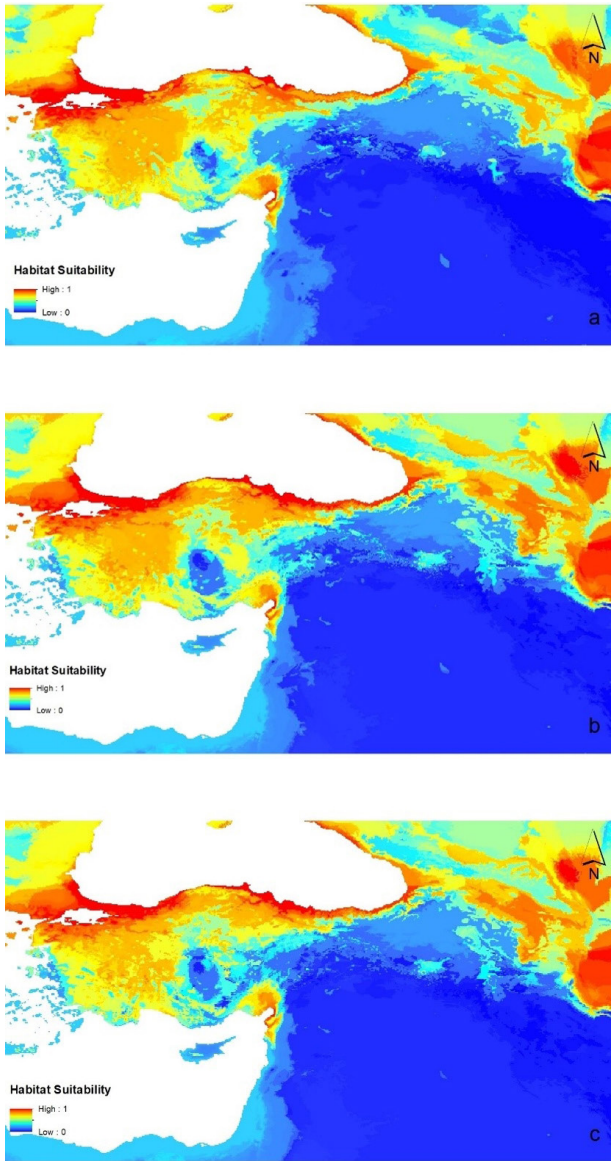

Figure 4. Ecological niche models showing the geographical distributions of *Harmonia axyridis* under a. current and the constructed future (b. the CNRM-CM6-1 SSP126; and c. CNMRM-CM6-1 SSP585) bioclimatic conditions.

warmest quarter) had the most contribution to the model predictions (Table 2).

Under current bioclimatic conditions, the model prediction was compatible with the known occurrence data of *H. axyridis*. Since there was no occurrence data around southeastern Turkey, the current prediction suggesting that the prediction is at equilibrium with climatic conditions. The future bioclimatic conditions under two different carbon emission scenarios showed a similar distribution, and the predicted suitable areas are relatively wider in the Black Sea region than the current distribution range. Moreover, the higher elevations are getting more suitable under both future predictions, while the Central Anatolia is less suitable. However, under the worst-case future scenario, the Central Anatolia is getting less suitable, while the higher elevations are getting more suitable.

Table 2. Contributions of bioclimatic variables to the model predictions.

Variable	Contribution (%)
Bio18	43.7
Bio7	37.1
Bio6	13.0
Bio15	6.2

3.1. Seasonality

According to the records in DoğalHayat and iNaturalist, the seasonal distribution of 93 records given at different dates from 62 locations was summarized in Figure 5. As a result of these records, *H. axyridis* was seen most of the year except for the cold January and February. Most of the recordings were obtained in the May and June period, the number of records decreased towards winter.

H. axyridis mostly preferred an elevation of 0–100 m a.s.l. According to 120 new and published records from Turkey, 54 records (45%) were up to 100 m from sea level. Seventeen records were between 100 and 200 m a.s.l. The species has not been determined between 1400 and 1900 m. It was vertically found up to 1994 meters in Hacıbaba Mountain (Karaman) (Figure 6).

4. Discussion

H. axyridis has been introduced throughout the world, either intentionally, or unintentionally through international transport since 1916 (Poutsma et al., 2008). In Europe, this species was first introduced as a biological control agent in France in 1982. Its mass production in France started in 1992. In this period, field experiments and releases were carried out between 1990 and 1997. After 1995, the ladybird was sold by various biological control companies in France, Belgium, and the Netherlands. Then it was also intentionally released in a dozen European countries (Coutanceau, 2006; Brown et al., 2008) and Egypt (El Arnaouty et al., 2000). After the species was released also in some other European countries and it was found in the wild in many Scandinavian and Western European countries. *H. axyridis* has spread very rapidly, particularly since 2002 and it is now regarded as established in most of the European countries. It is predicted that the spread and

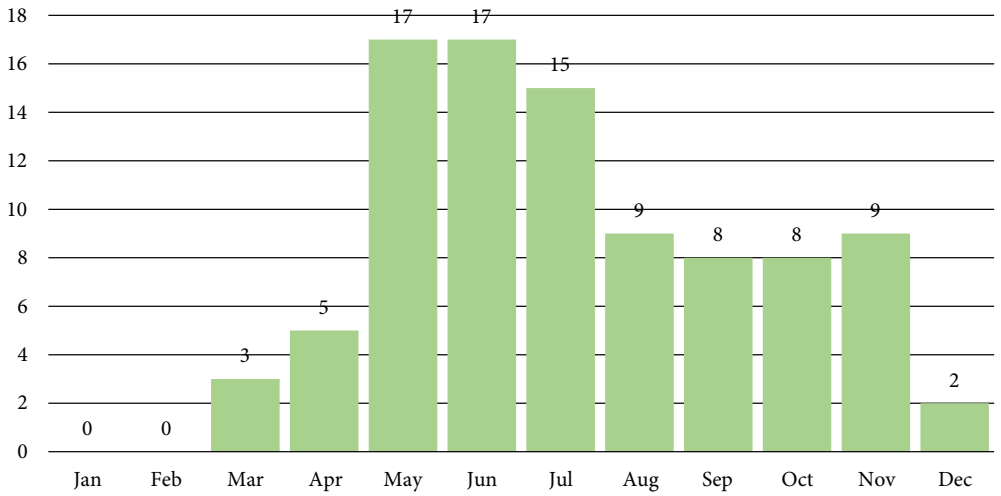

Figure 5. Seasonality of *Harmonia axyridis* in Turkey according to new records (93 records from 62 localities).

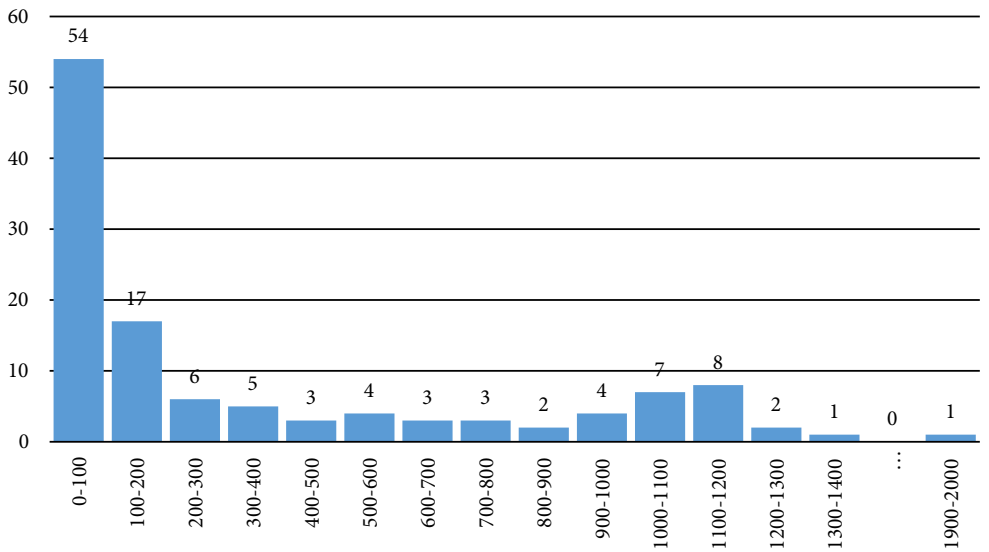

Figure 6. Vertical distribution of *Harmonia axyridis* in Turkey according to elevation groups per 100 m.

increase within Europe will continue and that *H. axyridis* will become one of the most widely distributed coccinellids in the continent (Brown et al., 2008; iNaturalist[2]).

The initial record in the Western Palaearctic region, except those in Europe, was from Egypt. Their origin was those brought from France to Cairo for biological control (El Arnaouty et al., 2000). The first sample of the species in Saudi Arabia was collected in 2005 and its origin was probably not from Europe but Africa and Asia (Biranvand et al., 2019). *H. axyridis*, recorded from Sozopol (Burgas) in Bulgaria in 2013, was for the first time collected in Iran, from the city of Rasht in Gilan province in April 2016 (Mardani-Talaee et al., 2019). The initial records and current distributions in other regions and countries such as the Caucasus, Romania, and Ukraine were summarized by Roy et al. (2016). Specimens first recorded in Turkey were collected in Tekirdağ province in 2011 by Aysal and Kıvan (2014). However, among the ones presented here as new location records, we have records in 2010, a year before those in Tekirdağ. This ladybug was first seen in Karaman (loc. 30) on November 2, 2010, and in Kemerburgaz (loc. 19) on November 5, 2010, three days later. Apart from those from Tekirdağ in 2011, the next two records were also from Karaman province. The first of them was from Ayrancı (loc. 31) in 2012 and the other from Bucakkışla (loc. 34) in 2013. A few months before the last, Bukejs and Telnov (2015) found the only individual of this species in Nevşehir province (loc. 90).

When we examine the history of published and new records given in Figure 1, it is seen that the route of invasion is probably from the west of Europe to the Balkans, from there to Turkish Thrace, then to other parts of Marmara and the Western Black Sea. The first observation in the Aegean Region, which is further south, was taken from İzmir in 2015. In accordance with the invasion route model, it was first seen in 2016 in Antalya, in the west of the Mediterranean.

On the other hand, it continued to move eastward along the Black Sea in the north of Turkey. The first findings from Samsun (loc. 51) and Sinop (loc. 52) in the Central Black Sea Region were obtained in 2016. The ladybug was first determined in the Eastern Black Sea region in 2018, in Rize (loc. 45) and Trabzon (loc. 58).

As described above, the oldest recording in Turkey from Tekirdağ in 2011, except one from Karaman in 2010 record, is proportional to the date of entry of species which spreads gradually from Western Europe through Central Europe and the Balkans to Turkey. However, the records in the central district of Karaman (loc. 30) in 2010, in Ayrancı district (loc. 31) in 2012, in Bucakkışla district (loc. 34) in 2013, and Göreme (Nevşehir) in 2013 are relatively earlier than expected. Karaman province is in the south of the Central Anatolia Region and Nevşehir is located in the middle of the same region. However, locality 27 in Karaman was the oldest of all records and dates from 2010. Therefore, the history of records in Central Anatolia does not comply with the above-mentioned distribution model, which extends from west to east from Western Europe to Turkey. In this case, it may be thought that the origin of invasion in Karaman is different or the species started to spread 5–10 years earlier than published observations in other regions.

According to the first case, the origin of the bug in Karaman is different from other provinces of Turkey, originated from Europe and may be of a different route, such as Africa and/or Asia.

According to the second scenario, the invasion of *H. axyridis* in Turkey probably began a few years before the first observations. Given this possibility, the species in Bulgaria and the European part of Turkey may have started occupation previously 5–10 years. Later, it probably expanded the distribution area from the west to the east along with the Black Sea Region in the north and to the south of the Aegean Region in the west.

McCorquodale (1998) calculated an estimated spread rate of 442 km/year in North America, whereas Brown et al. (2011) calculated that *H. axyridis* spread at a maximum rate of c. 200 km/year in Europe. In this case, *H. axyridis*, which entered the country in the early 2000s, may have reached Karaman in 4–5 years, according to the estimates of the spreading in the range of 200–442 km above.

According to the third and last scenario, Karaman is in the hinterland of Mersin and partly Antalya provinces, where intensive farming activities (especially greenhouse cultivation) are carried out, and these ladybirds are brought to fight against insects such as aphids may have escaped from the greenhouses and reached Karaman.

On the other hand, the frequency vertical distribution of *H. axyridis* from Turkey was investigated. According to the records between 2010–2020 (n = 120), this coccinellid was found between 1 and 1994 meters. It mostly (n = 54) preferred an elevation of 1–100 m a.s.l. In Slovakia, this beetle was recorded in altitudes ranging from 98 to 1250 m, with the highest point in Slovakia being 2654 m (Panigaj et al., 2014). The results from the two countries are similar and *H. axyridis* prefers lowland.

Finally, due to the invasive behavior of this species, new observations are recorded from new localities in Turkey and its surrounding. The recently obtained records which could not be used for the ecological niche models while preparing this paper, support our model predictions, which means that our current prediction is significant for this species. Also, our current modeling results support Poutsma et al. (2008) which have the first climatic suitability predictions for this species regarding Turkey. Moreover, Central Anatolia is getting less suitable and higher elevations are getting more suitable under both future predictions. Therefore, it is expected to get new records, especially from higher altitudes for the next 20 years.

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Supplement materials:

The Balkans & East European countries

ALBANIA (ARNAVUTLUK) [***Ar1***]: – **Durrës** [*1*], 17.VI.2019, "Arian"

BOSNIA AND HERZEGOVINA (BOSNA-HERSEK) [***BH1-3***]: –***Banja Luka***: 5 km NE [1], 8.VI.2019, "Nina St".–***Posavina***: Domaljevac [2], 3.VI.2020, "natdju"; Matici [3], 4.VI.2020, Silly Pancake.

BULGARIA (BULGARİSTAN) [***Bu1-18***] – ***Burgaz*** (centrum) [1], 30.VI.2020, "atanas_bodukov"; Primorsko [2] 17.XII.2019; 4.5 km N [3], 29.X.2018, "Katunchik (katya)"; Sozopol [4], 19.VI.2013, Ivan Tislenko. – ***Eski Cuma***: Popköy (Popova), Palamartsa [5], 14.VI.2020, Julie Butterworth. – ***Filibe*** (centrum) [6], 20.VII.2018, Cesar Pollo; 8.VI.2020, "tedo_4"; Kozanovo [7], 18.V.2019, "baigeorgi"; Kaloyanovo, Razhevo [8], 18.V.2020, Kenneth Woodcock. – ***Gabrova***: Trevne (Tryavna) [9], 13.VI.2020, H. Shishkov.– ***Hasköy*** (Haskova): Kenana [10], 14.VI.2020, "loraveleva". – ***Plevne*** (Pleven) [11], 15.VI.2020, Joanna Ivanova, 18.VI.2020, Kalina Ivanova.– ***Sliven***: Trapoklovo [12], 26.VI.2020, Ivan Zhelyazkov; Yeni Zağra "Nova Zagora" [13], 03.V.2019, "mstoyanova"; Korten [14], 26.V.2019, "mstoyanova". – ***Smolyan***: Döven (Devin) [15], 26.VI.2020, Penka Gerginska. –***Sofya*** (Sofia): Botevgrad (Orhanie) [16], 2.XII.2019, Edelvina Tsekova; ibid., 10.IV.2017, 14.VIII.2019, 13.III.2020, 21.III.2020, 13.VI.2020, 18.VI.2020, 22.VI.2020, 8.VII.2020, "exonie".– ***Varna*** (centrum) [17a], 30.VII.2020, Maria Yordanova; Primorski [17b], 12.VI.2020, Elena Dobreva. – ***Yukarı Cuma*** (Blagoevgrad): Petrich [18], 23.V.2020,Violeta Zhelyazkova.

CROATIA (HIRVATİSTAN) [***Hrv1-10***]: – ***Bjelovar-Bilogora*** (Bjelovarska-Bilogorska): Bjelovar [1], 27.V.2020, Tibor Pejic. – ***Dubrovnik-Neretva***: Mljet, Pomena [2], 2.IX.2016, Matthew O'Donnell. – ***Koprivnica-Križevci*** (Koprivničko-Križevačka): Koprivnica, Reka [3], 4.VII.2020, "emas". – ***Osijek-Baranja*** (Osjecko-Baranjska): Osijek [4], 11.V.2020, Alfredo Brumnić. – **Požega-Slavonia** (Požeško-Slavonska): Brestovac, Vranić [5], 9.XI.2019, Marko Doboš; Pleternica, Poloje [6], 28.X.2018, Marija Kovacevic. – ***Split-Dalmaçya***: Split [7], 17.IX.2018, Anton Gjeldum; Omiš [8], 23.III.2019, Anton Gjeldum; Vrgorac, Veliki Prolog [9], 30.VII.2019, "evabri". – ***Virovitica-Podravina*** (Viroviticko-Podravska): Rahoviçe (Orahovica), Duzluk [10], 9.V.2020, Marko Doboš.

GREECE (YUNANİSTAN) [***Gr1-21***]: –***Attika***: Islands, Egina (Aegina), Piraeus [1], 26.VII.2019, Manoli Strecker. – ***Central Macedonia***: Selanik (Thessaloniki), Selanik Int. Airport [2], 17.V.2019, "ekoliarou96"; Melissochori [3a], 1.XII.2018, 29.V.2019, 7.VI.2019, 20.VI.2020, "tikitu"; ibid., Monolofo [3b], 22.II.2019, "tikitu"; Halkidiki (Chalkidiki), Metagkitsi [4a], 27.IV.2019, "tikitu"; Mount Athos Bay [4b], 13.VIII.2018, Ioannis Giovos. – ***Epir*** (Epirus): Yanya [5], 27.VI.2020,Dimitris Kaskanis; Papingo [6], 27.VI.2017, "mbarger". – ***Girit*** (Crete) [7], 9.VII.2013, 14.IX.2013, Steve Daniels. – ***İyonya*** *(Ionian)* ***Islands***: Lefkada, Frini [8], 20.VI.2020, Papageorgiou Nikolaos; Apollonioi, Athani [9a], 25.VI.2019, 30.VI.2019, "Vasilikikorfiati"; Vasiliki [9b], 30.V.2019, Eirini Arvaniti; Korfu, Vitalades [10], 29.VII.2017, An-Tim. – ***North Aegean***: Midilli (Lesbos), Agiasos [11], 25.V.2019, Savvas Zafeiriou.– ***South Aegean***: Kiklad (Cyclades) islands, Serifos (Koyunluca), north of Panagia, [13], 24.VIII.2018, ibid., Psili Ammos Bay [14], 19.VIII.2018, Paolo Mazzei; Berre (Paros) Isl., Aliki [15], 13.VII.2017, Valia Pavlou, – ***Teselya*** (Thessaly): Yenişehir (Larissa) [16], 24.VII.2019, Papageorgiou Nikolaos; Golos (Volos) [17], 24.IV.2020, "chriskazil"; ibid., 29.IV.2019, Christos Karoulis; Liri [18], 29.VIII.2013, 9.IX.2013, 10.IX.2013, 17.IX.2013, 26.VII.2018, 17.VIII.2018, 2.X.2019, Chris Taklis; Trikala, Neraida [19], 6.VII.2020, Sofia Giakoumi.– ***Western Greece***: Ahaya (Achaea), Kalavryta, Lefkasio [12], 27.X.2017, Valia Pavlou; Etolya-Akarnanya (Aetolia-Acarnania), Vónitsa, Sáltini beach [20], 6.X.2019, Papageorgiou Nikolaos.– ***Western Macedonia***: Kesriye (Kastoria), Dubyak [21], 30.IV.2016, Kostas Zontanos.

HUNGARY (MACARİSTAN) [***Mac1-9***]: – ***Baranya***: Pécs [1], 5.IV.2020, Zsófia Varga. – ***Csongrád***: Mórahalm [2], 22.IV.2020, Gergely Gajda. – ***Fejér***: Sárbogárd, Vajta, Dél-Mezőföld Tájvédelmi Körzet [3], 20.X.2018, Csaba Rákász.– ***Pest***: Gyál, Bugyi [4], 8.V.2020, Attila Steiner. – ***Somogy***: Siófok [5], 26.VII.2020, Zsófia Varga. – ***Tolna***: Paks [6], 3.XI.2018, Peter Kiss.– ***Veszprém***: Balatonfüred, Vak Bottyán u. [7], 1.VI.2019, Attila István Pataki; Balatonszepezd [8], 26.V.2020, "mibnaturalist"; Balatonalmádi, Alsóörs [9], 8.VI.2019, Szabolcs Bártfaikiss.

ITALY [***it1-6***]: –***Apulia*** (Puglia): Bari, Gioia del Colle [1], 20.I.2020, Giuseppe Colangelo; Monopoli [2], 9.IX.2013 "memo"; Lecce, Acaya [3], 26.VII.2019, Fortunato Pititto; –***Taranto***: Castellaneta Marina [4], 3.V.2017, Stephen Moores; Leporano [5], 19.V.2019 "gianfrs". –***Calabria***: Catanzaro [*6*], 14.VII.2020, Aurora Morrone.

KOSOVO (KOSOVA) [***Ko1-4***]: – ***İpek*** (Pećki): Klina [1], 15.X.2019,Aleksander Golemaj. – ***Priştina*** (Priština) (centrum) [2], 15.X.2018, Engjëll Maliqi; 4.V.2019, 25.V.2019, 30.VI.2019, 18.VI.2019, Besnik Fetiu; 17.VI.2020, "corygiacobbe"; ibid., Keçekolle [3], 23.V.2020, 31.V.2020, 29.VI.2020, 16.VII.2020, Besnik Fetiu. – ***Prizren*** (centrum) [4], 10.VII.2019, Emrulla Spahiu.

MACEDONIA (MAKEDONYA) [***Mak1-3***]: – ***Kumanova*** [1], 5.V.2020, "crvenakalinka". – ***Ohri*** (Ohrid): Valestova [2], 25.V.2017, "Katunchik (katya)". – ***Radoviş*** [3], 6.VI.2020, Aleks Kareiants.

MONTENEGRO (KARADAĞ) [***KDğ1-2***]: –***Ülgün*** (Ulcinj): Utjeha [1], 21.VIII.2017, 23.VIII.2017, Davide. – ***Žabljak***: Virak [2], 27.V.2019, "gazdamilan".

ROMANIA [***Ro1-19***]: – ***Arad***: Zăbrani [1], 30.VI.2019, "mocuta". – ***Argeş***: Piteşti, Băbana [2], 12.X.2017, "pyxidium". – ***Brăila*** (İbrail): Brăila, Baldovineşti [3], 2.VI.2019, Paraschiv Valeriu. – ***Buzau*** (Buzău): Buzău [4] 5.VI.2020, "The Great Wolf"; Pârscov [5], 6.VII.2019, Ilie George. – ***Bükreş*** (Bucuresti): centrum [6a], 5.VII.2018, 8.VII.2018, 5.VII.2019, 26.V.2020 "danamihaimileazachi", ibid., Strada Nuvele [6b], 4.IV.2019, Denisa Voinea; ibid., north of int. airport [6c], 9.III.2019, George Ştefan Năzăreanu; 16.VI.2019, "Ionica Ionica"; west of Univ. Polytechnic Bucureşti [7], 6.VI.2020, Theodor Momete. – ***Călăraşi***: Cuza Vodă [8] 16.V.2020, Mihai Alexandru.– ***Caraş-Severin***: Coronini [9], 30.X.2019, Laurentiu Rozylowicz. – ***Gorj***: Pades, Lacul Valea Mare [10], 23.VII.2019, Will Earley. – ***Köstence*** (Constanţa): Agigea [11], 27.II.2020, Iulian Gherghel; Limanu [12], 29.VI.2019, "danamihaimileazachi". – ***Mehedinţi***: Mărăşeşti, Baia de Arama [13a], 12.VII.2020, "addanastase"; Ponoarele [13b], 11.VII.2019, Tobias Demetz. – ***Neamţ***: Roman

[14], 8.VI.2019 "naomi59".– ***Timiş***: Uivar, Rauti [15] 30.V.2015, Manuela Bacsik. – ***Tulça*** (Tulcea), Babadağ [16], 27.V.2019, "aatt"; Sfantu Gheorghe [17], 31.VII.2017, Dag Terje Filip Endresen. – ***Yaş*** (Iaşi), Yaş [18a], 26.VI.2020, Vlad-Corneliu Oancea; Bârnova [18b], 20.X.2019, "keppler". – ***Yergöğü*** (Giurgiu): Mihailesti, Popeşti [19], 16.VI.2020, Boss Tir.

SERBIA (SIRBİSTAN) [***S1-8***]: – ***Belgrad***: Banjica [1a], 30.V.2019, 1.VI.2019, Denis Ćoso, ibid., 22.VI.2019, "davidlupin7";Beli Potok [1b], 11.XI.2017, 25.I.2018, 19.V.2019, 3.VII.2019, 15.III.2020, Denis Ćoso; Novi Grad [1c], 2.VI.2019, Denis Ćoso, ibid., 7.VI.2020, Jovana Bila Dubaić.– ***Raški***, Kraljevo [2], 30.V.2019, Lukas Probst. – ***Nišava***: Niş (centrum) [3a], 12.IV.2019, "sanca13"; Durlan [3b], 25.V.2019, 28.VI.2020, 12.VII.2020, "sanca13"; Gornja Studena [4], 18.X.2019, "sanca13".– ***Zlatibor***: Užice, Drežnik [5], 17.VIII.2017, Denis Ćoso; Bajina Bašta [6], 23.V.2018, 3.VII.2018, "davidlupin7". – *VOYVODINA* - ***Güney Bačka***: Novi Sad [7], 1.V.2019, Diana Padrón. – ***Srednje-Banatski*** (Orta Banat): Zrenjanin [8], 20.III.2019, 13.V.2019, 25.V.2019, Ivan Pancic.

Ukraine & Kırım (Crimea)

UKRAINE [***Uk1-4***]: – ***Odessa***: Kyivsky [1], 2.VI.2020, Tatiana Sokolova-Yudina; Odessa (centrum) [2], 14.X.2019, "naturalist22272", 10.VII.2020, Ivan Vovk. – ***Mikolayiv***: Mikolayiv (centrum) [3], 4.VII.2016, 9.VII.2018, 16.VI.2019 "efarilis"; Tsentral'nyi [4], 29.IV.2019 "efarilis".

CRIMEA (KIRIM) [***Kr1-12***]: – ***Akmescit*** (Simferopol) [1] (centrum), 08.VI.2020, Dmitry Svobodin; ibid., 13.VI.2020, "diana_abdo"; Kyivsky [2], 28.VI.2019, Anatoliy Bondarenko. – ***Bahçesaray***: Alushta [3], 24.VI.2020, 01.VII.2020, 02.VII.2020, 03.VII.2020, Maxim Shumskikh; Simeiz [4], 21.VI.2019, Ilya Kasatov; Sudak [5], 14.VI.2016, Иван Тисленко; Yalta [6], 01.VI.2020, Mikhail Orlov.– ***Nyzhn'ohirs'kyi***, Piny [7], 30.VI.2020, Lyudmila Pugacheva.– ***Sivastopol*** (centrum) [8], 10.IV.2016, "vlad50".; ibid., 07.VI.2019, Sofia Pasechnaya; Balıklava [9], 14.V.2020, "ayvazktryan"; Gagarin [10], 01.IX.2019, Yulia Demidova, ibid., 15.V.2020, Polina Pushko; Kyzylove [11], 27.I.2018, Ivan Pristrem.– ***Soviets'kyi*** [12], 22.VII.2020, "tanya_blond".

The Caucasian countries

ABKHAZIA (ABHAZYA) [***Ab1***]: – ***Gudauta***: Yeni Afon (Akhali Atoni) [1], 21.VIII.2019, Vadim Yangunaev.

ADYGEY (ADİGEY) [***Adg1-4***]: – ***Adıgey*** *(Adygeysk)*: Teuchezhskiy [1], 12.VI.2020, Bassem Mansour. – ***Maykop*** (centrum) [2], 1.VIII.2013, Nikita Sevastianov; Kuzhorskaya [3], 17.VIII.2019, "bibina1"; Nikel' [4], 08.VII.2019, "staayaaaa108".

ARMENIA (ERMENİSTAN) [***E1-3***]: – ***Aragatsotn***: Artashavan [1], 29.XII.2019, "Artem"; Sasunik [2], 13.IV.2019, "artem". – ***Şirak*** (Sjirak) [3], 06.VII.2018, Andr Hospr.

CHECHNYA (ÇEÇENİSTAN) [***Çe1-2***]:– ***Bamut*** [1], 21.V.2020, Adam Makhauri.– ***Coharkale*** "Groznenskiy (Grozni)"[2], 09.XI.2019, Larisa Saparbayeva.

DAGHESTAN (DAĞISTAN) [***D1-2***] – ***Akhtynskiy***: Kurush [1], 19.VII.2020, Ramazan Murtazaliev. – ***Kaspiysk*** [2], 21.V.2019, Ksenia Igolkina "naturalistka".

GEORGIA (GÜRCİSTAN) [***G1-4***]: – ***Batum***: Chakvi-Makhinjauri tunnel Bypass Batum [1], 12.VI.2019, rec. krasky o. – ***Kaheti***: Telavi [2], 03.V.2019, Levan Ivanov. – ***Mtskheta-Mtianeti***: Mtskheta [3], 12.VI.2020, Natallia Nata. – ***Tiflis*** *(Tbilisi)* [4], 07.VI.2019, Felix Riegel.

KABARDIN-BALKAR [***KB1-3***]: – ***Babugent*** [*1*], 23.IX.2019, "bibina1".– ***Elbrus*** *"El'brusskiy"*: Neytrino [2], 05.VII.2020, Gennadiy Okatov.– ***Urvanskiy***: Argudan [3], 06.VI.2020, "dianbat".

KRASNADOR [***Kr1-10***]: – ***Gelendzhik*** [1], 21.V.2019, "kato01". – ***Krasnador*** (centrum) [2], 15.V.2019, 23.V.2019, Yuriy Danilevsky, ibid., 06.VI.2019, Julia Vasilieva, ibid., 30.V.2020, 18.VI.2020, Konstantin Perezhogin; Abinskiy [3], 19.X.2019, Anna Dokuchaeva; Dinskiy (Dinskaya) [4], 18.IV.2020, "Vladimir"; Platnirovskaya [5], 20.V.2019, "timocka"; Severskiy, Kholmskaya [6], 02.V.2020, Gennadiy Okatov; Ust-Labinsk [7], 05.V.2019, 10.V.2019, 25.V.2019, 02.VI.2020, Yuriy Danilevsky. – **Sochi** (centrum) [8], 30.VII.2019, Vasiliy Vasiliy; Denis Makhnovsky; Razdolnoye [9], 20.V.2020, Andrey Petakin; Estosadok [10], 15.XI.2018.

NORTH OSSETIA-ALANIA [***KO1***]: – ***Vladikavkaz***: Karmadon [1], 16.V.2019, Aleksey Sazhnev.

STAVROPOL (ŞETKALE) [***Sta1-3***]: – ***Pyatigorsk*** [1], 21.V.2020, Nikita Gerasin; ibid., 05.VII.2020, "a_ma_bird". – ***Suvorovskaya*** [2], 13.VI.2020, Nikita Gerasin. – ***Zheleznovodsk*** [*3*], 28.VI.2019, "druzhinka".

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IRAN [***Ir1***]: – ***Gilan***: Rasht [*1*] (Mardani-Talaee et al., 2019).

ISRAEL [***is1-6***]: – ***Northern District***: ***Akka*** (Akko)**:** Ein HaMifratz [1–4], 20.VIII.2018, 14.IX.2018, 6.X.2018, 8.III.2019, 15.III.2020, 13.IV.2020, 8.V.2019, 7.V.2020, 26.V.2020, 25.VII.2020, "centaur". – ***Central District***: Rehovot [5], 13.IV.2020, "amnonyarom". – ***Tel-Aviv*** (centrum) [6], 5.VII.2020, Omer Avi.