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# Emerald Ash Borer Approaches the Borders of the European Union and Kazakhstan and Is Confirmed to Infest European Ash

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**Citation:** Volkovitsh, M.G.; Bieńkowski, A.O.; Orlova-Bienkowskaja, M.J. Emerald Ash Borer Approaches the Borders of the European Union and Kazakhstan and Is Confirmed to Infest European Ash. *Forests* **2021**, *12*, 691. <https://doi.org/10.3390/f12060691>

Academic Editor: Young-Seuk Park

Received: 20 April 2021

Accepted: 24 May 2021

Published: 27 May 2021

**Abstract:** Emerald ash borer (EAB), *Agrilus planipennis*, native to East Asia, is an invasive pest of ash in North America and European Russia. This quarantine species is a threat to ash trees all over Europe. Survey in ten provinces of European Russia in 2019–2020 showed that EAB had spread faster and farther than was previously thought. The new infested sites were first detected in St. Petersburg (110–120 km from the EU border: Estonia, Finland) and Astrakhan Province (50 km from the Kazakhstan border). The current range of EAB in Europe includes Luhansk Province of Ukraine and 18 provinces of Russia: Astrakhan, Belgorod, Bryansk, Kaluga, Kursk, Lipetsk, Moscow, Orel, Ryazan, Smolensk, St. Petersburg, Tambov, Tula, Tver, Vladimir, Volgograd, Voronezh, and Yaroslavl. Within these, only seven quarantine phytosanitary zones in five provinces are declared by the National Plant Protection Organization of Russia. EAB was not found in the regions along the Middle Volga: Mari El, Chuvash and Tatarstan republics, Nizhny Novgorod, Samara and Saratov provinces. The infested sites in St. Petersburg and in the Lower Volga basin are range enclaves separated from the core invasion range by 470 and 370 km, correspondingly. It is possible that new enclaves can appear in the cities of Eastern Europe and Kazakhstan far from the current known range. All previously known infestations in European Russia were in green ash (*Fraxinus pennsylvanica*), which was introduced from North America, and individual trees of European ash (*F. excelsior*). A first confirmed case of mass decline of several thousand of EAB-infested European ash trees in Moscow province is provided. Therefore, there is no more doubt that under certain conditions EAB can seriously damage native ash trees in European forests.

**Keywords:** emerald ash borer; EAB; northwest Russia; St. Petersburg; southeast Russia; *Fraxinus excelsior*; European ash

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## 1. Introduction

Emerald ash borer (EAB), *Agrilus planipennis* Fairmaire, 1888 is one of the most devastating pests of ash (*Fraxinus* sp.) trees in the world [1–4]. Over the past few decades, from a little-known species whose native range was limited to East Asia [5], it has become one of the most dangerous invasive pests of forests and urban ash plantings in North America and European Russia. It was first detected outside its native range in the USA and Canada in 2002 [6,7], and in European Russia (Moscow City) in 2003 [8,9]. By late 2020, EAB was reported in five provinces of Canada, 35 states of the USA [10], 16 provinces of Central European Russia and one province of Ukraine [11], having killed millions of ash trees [1,3,9,11–14]. This pest is regarded as a serious threat to the ash trees all over Europe [14–22]. In 2018, the probability of its spread to Belarus, Ukraine, Estonia, Latvia and Lithuania by 2022 was estimated as 15–40% [23]. However, recent discoveries have shown that EAB spreads faster and farther than previously thought, since it was detected in Eastern Ukraine (Luhansk Province) in 2019 [24].

Until recently, it was considered that EAB was spreading to the northwest from Moscow as far as the city of Tver [25] and its further natural expansion was regarded as extremely doubtful due to extensive ash-free areas [9,26–28]. No one expected that EAB had already established itself in St. Petersburg, far from the known northwest borders of its invasive range in Tver Province. However, the first information that EAB could be responsible for ash decline in the Petrodvorets District of St. Petersburg was posted by tree protection volunteers on the internet in late summer 2020 [29]. Therefore, it was necessary to verify this information by surveying ash trees in the mentioned district and assessing the potential risks from the sudden expansion of EAB to the northwest by almost 500 km, approaching the EU borders. Survey results were briefly reported at the conference “Kataev Memorial Readings XI” [30,31]. In this article, the results are described in detail.

The distribution of EAB in the east of European Russia is still poorly known [11], so further survey is required to determine the eastern border of the pest’s invasive range.

EAB can infest all ash species native to Europe [32]. The only native species in the greatest part of European Russia is European ash (*Fraxinus excelsior* L.); the second native species, *Fraxinus angustifolia* Vahl, occurs only in the Caucasus, far from the current EAB range. European ash is rare in the center and north of European Russia. Therefore, most infestations have referred to the green ash (*Fraxinus pennsylvanica* Marsh), which was introduced from North America and widely planted in the cities and along the roadsides [1,9,11]. The information about infestation of *F. excelsior* by EAB was scarce and referred only to urban plantings and artificial shelterbelts, where *F. excelsior* was planted together with *F. pennsylvanica* [1,14]. There were no data about the impact of EAB on European ash in natural forests. Therefore, there was a great deal of uncertainty regarding the potential impact of EAB on native ash in European forests [1,11].

The internet publication of the employee of the Federal Forestry Agency “Russian Center for Forest Protection” (“Roslesozaschita”) reported the severe damage by EAB to European ash in Kokinskij Forest nearby Ozherelie railway station, Kashira District of Moscow Province in 2014 [33]. However, this information was not officially confirmed by the National Plant Protection Organization of Russia (“Rosselkhozadzor”) and no quarantine phytosanitary zone was declared there [34]. Therefore, the survey of this forest stand was needed to assess if European ash trees were infested by EAB and how severe was the damage if any.

The objectives of the present study are as follows:

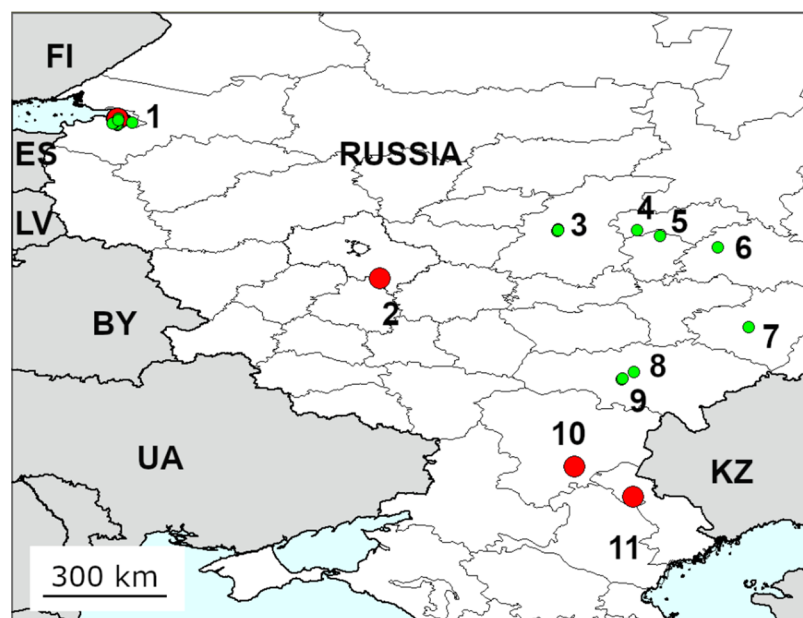
1. To assess if EAB had really spread to the northeast of European Russia as far as the city of St. Petersburg and if there were other infested sites in the city and adjacent districts of Leningrad Province.
2. To find out if the eastern border of the invasive range reached the Middle Volga Basin.
3. To check out if EAB moved further south of the previously known southern border of the range in the Lower Volga Basin.
4. To determine if EAB could severely damage forest stands of European ash.

## 2. Materials and Methods

In 2019–2020, ash trees in ten provinces of European Russia extending from St. Petersburg City and Leningrad Province in the northwest to Samara Province in the east and Astrakhan Province in the southeast were surveyed (Figure 1).

The first discovery of the EAB-infested ash trees in Martyshkino settlement (part of Lomonosov town, Petrodvorets District of St. Petersburg City) (Figure 1) was made in late August, 2020 [35], later exit holes in the ash bark, dead EAB adults and other infestation signs were found in this locality [36]. This locality was repeatedly visited by the first author during September–November 2020 and more proofs of EAB infestation including larvae were found there. Some more EAB infested green ash trees (*F. pennsylvanica*) with exit holes were found along Gostilitskoe Hwy (about 4 km southward of the first locality). In addition, the roadside plantings of *F. pennsylvanica* and *F. excelsior* in 8 localities along the route Ropsha–Kipen–Ropsha–Orzhitsy–Vilpovitsy–Gostilitsy in Leningrad Province, and

Lomonosov–Staryi Peterhof in Petrodvorets District of St. Petersburg, as well as stands of native *F. excelsior* along the Baltic–Ladoga glint near Vilpovitsy were surveyed (Table 1, localities 4–11). One locality with declined green ash trees along Pulkovskoe Hwy was also inspected (Table 1, locality 12). Meanwhile, one more EAB-infested locality in Staryi Peterhof (about 4 km eastward of first locality) was reported [35,37].



**Figure 1.** Surveyed sites of ash trees in European Russia in 2019–2020. Red circles—EAB is detected, green circles—EAB is not detected. 1—St. Petersburg City, 2—Kokinskij Forest nearby Ozherelie railway station (Moscow Province), 3—Nizhny Novgorod City, 4—Kozmodemyansk Town (Mari El Republic), 5—Cheboksary City (Chuvash Republic), 6—Kazan City (Tatarstan Republic), 7—Samara City, 8—Saratov City, 9—Usovka Island (Saratov Province), 10—Volgograd City, 11—Nikolskoe Village (Astrakhan Province). FI—Finland, ES—Estonia, LV—Latvia, BY—Belarus, UA—Ukraine, KZ—Kazakhstan.

**Table 1.** Results of the survey of ash trees in St. Petersburg City and Leningrad Province (1), Moscow Province (2) and along the Volga River (3–11) in 2019–2020.

Site Number (Figure 1)	Locality Number	Locality	Site Description	Signs and Symptoms of EAB Infestation
1	1	Martyshkino	<i>F. pennsylvanica</i> , few <i>F. excelsior</i> , roadside plantings	Crown dieback; EAB exit holes, bark cracks, larval galleries, adults and larvae
1	2	Lomonosov, Gostilitskoe Hwy	<i>F. pennsylvanica</i> , roadside plantings	Fading foliage, EAB exit holes
1	3	Staryi Peterhof, Suvorovskaya str.	<i>F. pennsylvanica</i> , roadside plantings [35,37]	Crown dieback, EAB exit holes [35,37]
1	4	Staryi Peterhof, Sergievka	<i>F. pennsylvanica</i> , roadside plantings	No EAB signs
1	5	Staryi Peterhof, Lugovoi park	<i>F. pennsylvanica</i> , roadside plantings	No EAB signs
1	6–7	Vilpovitsy	<i>F. excelsior</i> , village plantings, self-seeding	No EAB signs
1	8	Orzhitsy	<i>F. excelsior</i> , village plantings, self-seeding	No EAB signs
1	9	Bol'shoe Zaborodie	<i>F. pennsylvanica</i> , roadside plantings	No EAB signs

Table 1. Cont.

Site Number (Figure 1)	Locality Number	Locality	Site Description	Signs and Symptoms of EAB Infestation
1	10	Kipen'	<i>F. excelsior</i> , roadside plantings	No EAB signs
1	11	Ropsha and Bol'shie Gorki	<i>F. excelsior</i> , roadside plantings	No EAB signs
1	12	St. Petersburg City, Pulkovskoe Hwy	<i>F. pennsylvanica</i> roadside plantings	No EAB signs
2		Kokinskij Forest, Kashira District, Moscow Province	<i>F. excelsior</i> stand	Severely damaged, numerous EAB signs
3	1	Nizhny Novgorod City (Sluda, Georgievsky descent)	<i>F. excelsior</i> in riparian forests	No EAB signs
3	2	Nizhny Novgorod City (different districts)	<i>F. pennsylvanica</i> , street plantings	No EAB signs
4		Kozmodemyansk Town (different districts)	<i>F. pennsylvanica</i> , street plantings	No EAB signs
5		Cheboksary City (different districts)	<i>F. pennsylvanica</i> , street plantings	No EAB signs
6		Kazan City (river station, Tatarstan Street, Nizhnij Kaban Lake)	<i>F. pennsylvanica</i> , street plantings	No EAB signs
7		Samara City (river station)	<i>F. pennsylvanica</i> , street plantings	No EAB signs
8		Saratov City (different districts)	<i>F. pennsylvanica</i> , street plantings	No EAB signs
9		Usovka Island (Saratov Province)	<i>F. pennsylvanica</i> (invasive) in riparian fores	No EAB signs
10		Volgograd City (river station)	<i>F. pennsylvanica</i> , street plantings	Trees dead or severely declined, EAB exit holes, larval galleries, dead adult
11		Nikolskoe village (Astrakhan Province)	<i>F. pennsylvanica</i> , village plantings	One tree with EAB exit holes, larval galleries, dead adult

In 8–19 August 2020 ash trees in eight localities in Volga Federal District and Southern Federal District were surveyed: Nizhny Novgorod (Nizhny Novgorod Province), Kozmodemyansk (Mari El Republic), Cheboksary (Chuvash Republic), Kazan (Tatarstan Republic), Samara (Samara Province), Saratov (Saratov Province), Volgograd (Volgograd Province) and Nikolskoe (Astrakhan Province) (Figure 1, Table 1, sites 3–11). Only two EAB-infested sites in the Volgograd City and Astrakhan Province were found.

On 31 August 2019 the European ash stand in Kokinskij Forest that belonged to Stupino forestry nearby Ozherelie railway station, Kashira District of Moscow Province was inspected (Figure 1, Table 1, site 2). This part of the forest (about 10.6 ha) consisted mainly of *F. excelsior*. The general condition of this forest was assessed and the bark of several hundred of these trees on the southeastern edge of the site (54.7766 N, 38.2624 E) was examined.

The geographic and other data of all the sites (infested and not infested) explored in 2019 and 2020, number of examined trees, the kind of plantings and other details were placed in an Excel table (Table S1) and detailed location maps were made using DIVA-GIS 7.5 software [38]. The sources of the background maps are DIVA-GIS open data and OpenStreetMap [39].

### 3. Results

#### 3.1. Results of the Survey of Ash Trees in St. Petersburg City and Leningrad Province

Overall, three EAB infested localities were found, all in the Petrodvorets District of St. Petersburg City. The survey results of ash trees in St. Petersburg City and Leningrad Province are summarized in Table 1 (Site 1, localities 1–12).

EAB was detected in St. Petersburg for the first time in 2020. Clear signs of EAB infestation (exit holes, larval galleries, dead beetles, larvae) were found only in the Petrodvorets District of St. Petersburg City: Martyshkino, Lomonosov, Staryi Peterhof (Figure 1, Table 1, localities 1–3). No signs of EAB presence were detected in the other locations, neither in urban/village and roadside plantings of *Fraxinus pennsylvanica* and *F. excelsior* nor in the native and self-seeding trees of *F. excelsior* along the Baltic–Ladoga glint (Table 1, localities 4–11). The mortality of roadside plantings of *F. pennsylvanica* along Pulkovskoe Hwy (Table 1, locality 12) resulted from water imbalance.

Locality 1, details. St. Petersburg City, Petrodvorets District, Martyshkino, Morskaya Street near the intersection with Zhora Antonenko Street, 59.9016 N, 29.8187 E, visited 2 and 27 September, 14 October and 27 November 2020. The site, about 1.2 km long, extended along Morskaya Street from the intersection with Zhora Antonenko Street to about the intersection with Kristatel'ka River (Sergievka Park). The area examined included one-row of multiple-aged roadside tree plantings of green ash (*Fraxinus pennsylvanica*), and, to a much lower extent, European ash (*F. excelsior*), and nearly all of them demonstrated signs of EAB damage. From the abundance of exit holes on the trunks, peeling of bark and multiple bark cracks, this EAB outbreak site had likely existed for several years (see [28,31]), given that the majority of exit holes and larval galleries were made in previous years. Current-year larval galleries were seen on a stump of a recently sawn ash tree and two EAB larvae were extracted from the trunk of a small green ash which proved that the outbreak site was still active. Preliminary inspection demonstrated greater damage of young trees on well-insolated spots than on heavily shaded spots and also more EAB damage to green ash compared to European ash (see Section 3.3).

Locality 2, details. St. Petersburg City, Petrodvorets District (on the border with Leningrad Province), Lomonosov, Gostilitskoe Hwy, 59.866668 N, 29.817379 E, visited 27 September and 14 October 2020. The site extended about 350 m long along Gostilitskoe Hwy (road 41K-008) between a gas station and the belt-way (KAD) entrance. The area included one row of middle-aged roadside green ash. EAB exit holes were found on a few of them.

Locality 3, details. St. Petersburg City, Petrodvorets District, Staryi Peterhof, Suvorovskaya Street, 59.8833 N, 29.8664 E; visited several times during September 2020 [35,37]. The site is located in a common courtyard of the three apartment buildings on Suvorovskaya Street. According to P. Batalov and G. Runov, who independently explored this site, there were several drying ash trees, some of them dead, with numerous EAB exit holes [35,37].

#### 3.2. Results of Survey of Ash Trees in the Localities along the Volga River

According to our observations, *F. pennsylvanica* is one of the most common trees planted in the cities of this region. In addition, it is an invasive plant which forms riparian forests along the Middle and Lower Volga River. The native *F. excelsior* is also common in the riparian forests but is rarely planted in the cities. The results of the survey in this region are presented in Table 1 (sites 3–11). EAB was not found in the Middle Volga region (Figure 1, Table 1, sites 3–9), but it was detected in two localities in the Lower Volga region (Figure 1, Table 1, sites 10,11).

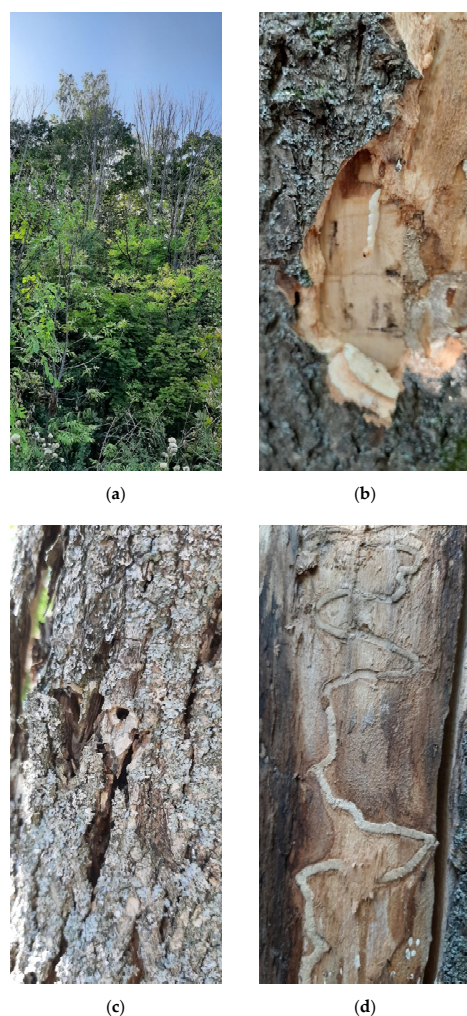
The survey of ash trees in the City of Volgograd (Figure 1, site 10) was made on 11 August 2020 in the area near the river station; *F. pennsylvanica* was common in this area, and most trees were damaged by EAB. In particular, the alley along the embankment consisted of dead or severely declined *F. pennsylvanica* trees with the exit holes and larval galleries. A dead EAB adult was collected in the bark in the courtyard of a house located on Lenin Avenue.



More than a hundred trees of *F. pennsylvanica* were examined in Nikolskoe village and its vicinity (Enotaevka District of Astrakhan Province, Figure 1, site 11) on 13 August 2020. One tree with EAB exit holes was found within 150 m from the Volga River (47.758379 N, 46.422687 E) and one dead adult was collected from the exit hole.

### 3.3. Results of the Survey of European Ash (*Fraxinus excelsior*) Forest Stand in Moscow Province

The southeastern part of Kokinskij Forest near Ozherelie railway station (Figures 1 and 2; Table 1, site 2), where the severe damage of European ash trees by EAB was detected in 2014 [33], was surveyed on 31 August 2019. According to our observations, this forest stand consisted of several thousand European ash trees about 60 years old. The photos on the satellite layer in Google maps [39] show that the trees grow in parallel rows, therefore these ash trees were planted. The area occupied by *F. excelsior* planting is 10.6 ha. There are no roads or paths in this part of the forest. Survey has shown that almost all trees there were severely damaged by EAB. The upper parts of the crowns were dead. Many ash trees were standing dead or had already fallen of wind. The examination of several hundred trees has shown that all of them had EAB larval galleries under the bark and exit holes on the bark. Three larvae and two adults that had died in exit holes were collected. It should be noted that the ash trees in Kokinskij Forest had the signs of damage not only from EAB, but also from bark beetles (presumably *Hylesinus varius* Fabricius). The roadside planting of *F. pennsylvanica* situated about 1 km from Kokinskij Forest was also severely damaged by EAB.

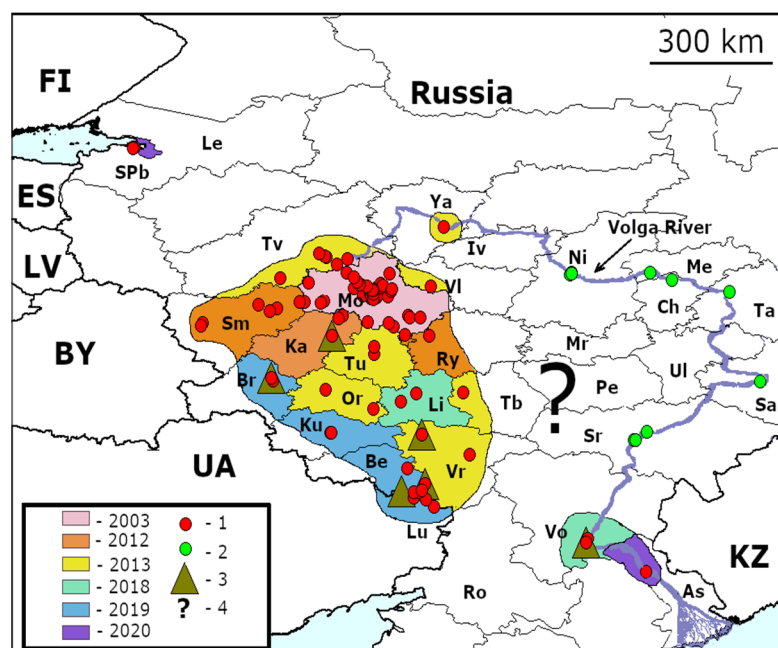


**Figure 2.** Signs and symptoms of EAB infestation of *Fraxinus excelsior* trees in Kokinskij Forest of Stupino Forestry near Ozherelie railway station (Kashira District, Moscow Province). (a) Trees with the upper part of main stems dead; (b) larva under the bark; (c) exit hole; (d) larval gallery.

#### 4. Discussion

##### 4.1. Current Range of EAB in European Russia and Ukraine

By 2020, EAB was detected in Luhansk Province of Ukraine and 16 regions of European Russia (Figure 3): Belgorod, Bryansk, Kaluga, Kursk, Lipetsk, Moscow, Orel, Ryazan, Smolensk, Tambov, Tula, Tver, Vladimir, Volgograd, Voronezh and Yaroslavl provinces [11]. Our findings of 2020 have shown that the invasive range of EAB continues to expand to the northwest (St. Petersburg City) and southeast (Astrakhan Province) of European Russia.



**Figure 3.** The known range of EAB in European Russia and Ukraine (as of April 2021). Regions of the range are colored according to the year of the first EAB detection in the province as indicated in the legend. 1—localities of EAB detection (Sources of information: [11] and the present study). 2—localities where EAB was not detected in 2020. 3—official quarantine phytosanitary zones declared by National Plant Protection Organization (“Rosselkhoz nadzor”) by March 2021 [34]. 4—eastern territories where EAB has not been detected, and no negative data were reported in the last three years. FI—Finland, ES—Estonia, LV—Latvia, BY—Belarus, UA—Ukraine, KZ—Kazakhstan, As—Astrakhan, Be—Belgorod, Br—Bryansk provinces, Ch—Chuvash Republic, Ka—Kaluga, Ku—Kursk, Le—Leningrad, Li—Lipetsk, Lu—Luhansk provinces, Me—Mari El Republic, Mo—Moscow Province, Mr—Mordovia Republic, Ni—Nizhny Novgorod, Or—Orel, Pe—Penza, Ro—Rostov, Ry—Ryazan, Sa—Samara, Sm—Smolensk provinces, SPb—St. Petersburg City, Sr—Saratov Province, Ta—Tatarstan Republic, Tb—Tambov, Tu—Tula, Tv—Tver, Ul—Ulyanovsk, Vl—Vladimir, Vo—Volgograd, Vr—Voronezh, Ya—Yaroslavl provinces.

It should be noted that, before 2013 when EAB was at last included into the list of quarantine pests in Russia [40], its spread was in fact monitored by mainly scientists from the Russian Academy of Sciences, St. Petersburg State Forest Technical University and amateur entomologists who understood the threat of invasion. Unfortunately, by 2021, the situation has not significantly changed. There are only seven official EAB quarantine phytosanitary zones in five provinces of European Russia [34] in spite of the much wider distribution of this pest in the country (Figure 3).

During the first nine years after the initial detection of EAB in European Russia (2003–2011) its known range was restricted to Moscow City and Moscow Province [1,3,8,9,14]. Then, in the next nine years (2012–2021) the known invasive range expanded to at least 18 provinces of Russia and reached Ukraine [11–13,24–26,28,30,41,42]. This clearly indicates the drastic increase in the speed of the EAB invasion.

Until recently, the range expansion of EAB in European Russia from the supposed primary infestation site, Moscow City, was recorded mainly in the southern (Belgorod, Voronezh provinces, east of Luhansk Province of Ukraine) and southeastern directions (Tambov and Volgograd provinces) and, to a much lesser extent, to the north (Yaroslavl Province), northwest (Tver Province), and west (Bryansk and Smolensk provinces) [1,9,11,13,14,41] (Figure 3). The probability of EAB spread to Belarus, Ukraine, Estonia, Latvia and Lithuania by 2022 was estimated as 15–40% [23]. Taking into account that the northern border of the EAB range is most likely limited by the minimum January temperatures of  $< -34^{\circ}\text{C}$ , in terms of climatic parameters, a significant part of Northern Europe is quite suitable for EAB colonization [43]. Nevertheless, Tver Province was considered for a long time to be the northwestern border of the EAB range in Europe and in recent years there has been only a minor advance in the northwest direction from Tver [12,28,42,44,45]. According to many authors, the further natural spread of the EAB towards St. Petersburg was strongly limited by the scarcity of ash stands of cultivated (only within settlements) and wild-growing trees, separated by extensive forest and marsh ash-free spaces [9,27,28,46–48]. Unfortunately, this opinion did not take into account the ability of EAB to spread by road and rail transport [28,49–51]. Nevertheless, the monitoring of ash plantings in different districts of St. Petersburg and Leningrad Province has not detected any signs of EAB presence up to 2020 [9,11,46].

Based on internet photos of the EAB site in Martyshkino (Figure 1, site 1) which were made during several previous years, the signs of the EAB infestation can be seen as far back as 2016, while the primary infestation from the active outbreak sites in Moscow and Tver provinces could have taken place in the mid-2010s [28,31]. Most likely, EAB has spread by rail or automobile transport [28,49–51].

The northernmost known locality of EAB in Asia is Troitskoe, Khabarovsk Territory (the latitude is 49.4 N) [5] and northernmost known locality in North America is Winnipeg (the latitude is 49.8 N) [10]. Therefore, the discovered EAB locality in Petrodvorets District of St. Petersburg City (the latitude is 59.9 N) is currently the northernmost known locality of this species in the world. However, the climate there is comparatively mild: the mean day temperature of the coldest month in Petrodvorets District is about  $-4^{\circ}\text{C}$ , i.e., even higher than in Tver ( $-8^{\circ}\text{C}$ ) and Moscow ( $-7^{\circ}\text{C}$ ) [52].

The presence of EAB infested sites in the Petrodvorets District of the St. Petersburg City directly endangers the unique palace and park ensembles of Peterhof (Sergievka park directly contacts the infested site) and Oranienbaum (about 5 km), the objects of UNESCO World Heritage. Moreover, since the border of the EAB invasive range has shifted about 500 km to the northwest and now it is only about 110 km from the Estonian and 120 km from the Finnish border (Figures 1 and 3), the threat of EAB invasion to European Union countries has drastically multiplied.

The first detected EAB locality in Astrakhan Province is the southernmost and the easternmost known locality of EAB in European Russia and Europe (Figure 3). The expansion of the EAB range southeastward to Astrakhan Province, about 170 km apart from the last detected invasion sites in Volgograd, is expected and corresponds to the main southeastward vector of the EAB invasion in European Russia. Both ash species: introduced *F. pennsylvanica* and native *F. excelsior* are very common in riparian forests along the Middle and Lower Volga River. Therefore, the appearance of EAB in the Volga valley in Volgograd and Astrakhan provinces means that the pest will inevitably spread in these forests along the river. It poses a threat to the ecosystems of the number of nature reserves, in particular Astrakhan Nature Reserve in the Volga delta. The detection of infested green ash sites only 50 km from the Kazakhstan border poses a direct threat of EAB invasion in this country in the nearest future.

No EAB infestations were detected in the regions along the Middle Volga: Nizhny Novgorod Province, Mari El, Chuvash and Tatarstan republics, Samara and Saratov provinces. Therefore, the current known eastern border of the invasive range is still the same as in 2013–2014 and passes through Yaroslavl City, the west parts of Vladimir, Ryazan and Tambov provinces and Voronezh City (Figure 3). However, the large territory between the



Volga River and the known EAB range has not been surveyed. Therefore, it is quite possible that EAB has spread to the east further than is known. The surveys in the following regions are necessary to reveal the real eastern border of the range: east of Vladimir, Ryazan and Tambov provinces, Ivanovo Province, west of Tatarstan and Mordovia republics, Penza, Ulyanovsk, Saratov and Volgograd provinces, and north of Rostov Province.

#### 4.2. The EAB Range Enclaves

The distance between the EAB infested sites in St. Petersburg and the closest known infested localities is more than 470 km. Therefore, this northernmost locality should be regarded as a range enclave. Likewise, the localities of EAB in the Lower Volga basin (Volgograd Province and north of Astrakhan Province) also form a range enclave. The distance between this enclave and the nearest known infested localities is more than 370 km. No signs of EAB were detected in ash stands between (Rostov provinces and east of Voronezh province) in 2019 [11]. It is also known that EAB infestations in Yaroslavl City are a range enclave separated from the core part of the range by EAB-free territories in spite of the presence of ash trees in these territories [41]. Formation of enclaves outside of the main EAB invasive range is well known in USA [50]. It is not surprising that such enclaves appeared in large cities like St. Petersburg, Yaroslavl and Volgograd. First, ash trees (mainly *F. pennsylvanica*) are very common in urban plantings of these cities, while they are rare in the surrounding territories. Second, large cities are transport hubs; therefore, the probability of the unintentional pest introduction by transport is high [28]. It is quite possible that these EAB enclaves appeared as a result of “hitch-hiking” in trains or cars which is regarded as a dispersal pathway for adult emerald ash borer in North America [51]. Third, the mean air temperature in large cities is usually slightly higher than in the surrounding territories, which could potentially facilitate EAB establishment in cities to the north (St. Petersburg and Yaroslavl).

The existence of three distant EAB enclaves in European Russia clearly indicates the possibility that EAB can appear in the other countries rather far from the borders of the core range. The probability of the enclave appearance is especially high in the large cities situated less than 500 km from the core range: Minsk, Kiev, Kharkiv, Vilnius, Riga, Tallin, Helsinki, etc. The approach to surveillance of EAB in Europe has been recently developed by European Food Safety Authority [53]. The innovative methodology for environmental risk assessment to EAB in Europe has been developed by Schrader et al. [54].

#### 4.3. On the Suitability of European Ash for the EAB Infestation and the Reality of the Threat to Forest Ash Stands in Europe

Thus far, most EAB records in European Russia reported damage to green ash (*F. pennsylvanica*) in urban and roadside plantings but, according to numerous sources [9,12,13], EAB could also infest, though to a lesser extent, European ash (*F. excelsior*).

Kokinskij Forest in Moscow Province is so far the only examined forest stand of European ash within the range of EAB. The infested shelterbelt of green ash along the railway is located only 1 km from this site and this likely was the source of infestation [33]. In 2014 about 50% of European ash trees there had EAB infestation signs [33]. Now almost all trees in this locality are severely damaged or killed by EAB. The survey of other European ash forest stands within EAB range is necessary to assess whether they also suffered of EAB infestation and, if so, how much is a damage.

## 5. Conclusions

1. The discoveries of Emerald ash borer, *Agrilus planipennis*, a notorious quarantine pest of ash trees in St. Petersburg and Astrakhan Province have shown that in European Russia it spreads faster and farther than previously thought.
2. The presence of EAB infested sites in the Petrodvorets District of the St. Petersburg City directly endangers the unique palace and park ensembles of Peterhof and Oranienbaum, the objects of UNESCO World Heritage. The presence of the EAB in-

- fested site in the floodplain of Lower Volga River endangers ecosystems of Astrakhan Nature Reserve and other protected areas in the Volga delta.
3. The northwestern limits of EAB invasive range shifted about 470 km to the northwest and now it is only about 110 km from the Estonian and 120 km from Finland borders, thus threat of EAB invasion to European Union countries has drastically multiplied.
  4. The expansion of the EAB invasive range southeastward to Astrakhan Province corresponds to the main vector of the EAB invasion in European Russia. Detection of infested sites only 50 km apart the Kazakhstan border poses a direct threat of EAB invasion in that country soon.
  5. By early 2021, EAB was detected in one province of Ukraine and 18 provinces of European Russia. However, the real range could be even wider, since it is still poorly studied. The eastern border of the range is unknown, but, according to our observations, it still has not yet reached the Middle Volga basin.
  6. Formation of the range enclaves far from the core area is typical for EAB invasion in European Russia, as was reported earlier in North America. Such enclaves are known in the St. Petersburg, in Yaroslavl and in the Lower Volga basin. Therefore, it is quite possible that the pest could be detected in other countries far from the borders of the core range, in particular in large cities.
  7. Documented evidence of colonization of the planted forest stands of European ash in Moscow Province stresses the reality of the threat to European ash in forests all over Europe.

**Supplementary Materials:** The following are available online at <https://www.mdpi.com/article/10.3390/f12060691/s1>, Table S1: Excel table with all mapped localities.

**Author Contributions:** Conceptualization, M.J.O.-B.; methodology, M.G.V., A.O.B.; investigation, M.G.V., A.O.B., M.J.O.-B.; writing—original draft preparation, M.G.V.; writing—review and editing, M.J.O.-B.; visualization, M.J.O.-B.; funding acquisition, M.J.O.-B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The study by M.J.O.-B. and A.O.B. was funded by the RUSSIAN SCIENCE FOUNDATION, grant number 21-74-20001. The study by MGV was undertaken within the framework of the State Project no. AAAA-A19-119020690082-8, is widely based on the Bioresource collection of ZIN and supported by the Russian Foundation for Basic Research, grant no. 19-04-00565-A.

**Data Availability Statement:** No new data were created or analyzed in this study. Data sharing is not applicable to this article.

**Acknowledgments:** We would like to thank the tree protection volunteers, P. Batalov, G. Runov, and D. Suslov who first detected ash dieback in the Petrodvorets District of St. Petersburg City and performed the preliminary examination of EAB infested sites; our colleagues A. Kovalev, S. Andreeva (Zoological Institute RAS), G. Konechnaya (Botanical Institute RAS), and A. Selikhovkin (St. Petersburg State Forest Technical University) who participated in the inspection of these sites and in the searches of new ones in St. Petersburg City and Leningrad Province. We are greatly thankful to two anonymous reviewers for their detailed comments and valuable suggestions.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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