


Communication

North-Westward Expansion of the Invasive Range of Emerald Ash Borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) towards the EU: From Moscow to Saint Petersburg

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Abstract: *Agrilus planipennis* is a devastating invasive pest of ash trees in European Russia, Ukraine, and North America. To monitor the north-western limit of its European invasive range, in June 2018 we established 10 study plots along the federal highway M10 (Russia) that runs between Moscow and Saint Petersburg through Tver' City (approx. 180 km from Moscow), and lined with ash trees. On each plot, 2–4 *Fraxinus pennsylvanica* trees with heights ranging 6.1–17.0 m and diameters ranging 7.0–18.0 cm were girdled, i.e., 50 cm of their bark were removed. The study plots were visited and girdled trees were examined in September and November, 2018, and in October, 2019. Observations revealed that the current continuous north-western limit of *A. planipennis* range in European Russia coincides with the north-western border of Tver' City and this range limit has not distinctly shifted north-westward during 2015–2019. In spite of the rich food supply (due to abundant *F. pennsylvanica* and *F. excelsior* plantings) in Tver' City and along roads going to and from, the population density of *A. planipennis* in the area is currently low. Recent (September 2020) sudden detection of a spatially isolated *A. planipennis* outbreak approx. 520 km far north-westward from Tver' (in Saint Petersburg) suggested that *A. planipennis* most likely had arrived at Saint Petersburg not by gradual stepwise (flying tree-to-tree) expansion of its continuous invasive range in Tver' City, but as a result of its accidental introduction by means of, e.g., “insect-hitchhiked” vehicles, transported plants for planting, and/or other commodities. The proximity of the reported *A. planipennis* outbreak to the borders of the EU (approx. 130 km to Estonia and Finland) requires urgent measures for its containment and control, and constant monitoring.

Keywords: ash; forest health; *Fraxinus*; invasive pest; pest insects; range expansion

1. Introduction

The emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) is a devastating invasive pest of ash trees in European Russia, Ukraine, and North America [1–5]. EAB is a beetle native to East Asia where it is considered a minor pest, colonizing dying ash and causing insignificant damage to viable trees. It was first detected in North America (southeast Michigan) in 2002, having been accidentally introduced with wood trade in the early 1990s, and has since killed millions of ash trees in forest, riparian, and

urban settings. In the most affected areas, more than 99% of ash trees with stem diameters greater than 2.5 cm have been killed. As a result of the invasion, the possibility cannot be excluded that EAB could eliminate one of North America's most widely distributed tree genus, with devastating economic and ecological impacts [2].

In 2003, *A. planipennis* was recorded for the first time in Moscow. It shortly produced a massive outbreak in the city, killed most of the ash trees in parks and roadside hedges, and started a rapid spread from Moscow in all directions [1,3,4]. By 2020, the pest was recorded in 16 provinces [= 'oblast'] of European Russia, towards the west approaching the border of Belarus and in the south-west invading eastern Ukraine, while in the north-western direction EAB was closing to the boundaries of Leningrad Province [5,6]. A statistical model developed in 2017 suggested that in a few years the invasive European range of *A. planipennis* would expand significantly and the pest would reach the borders of EU countries [7].

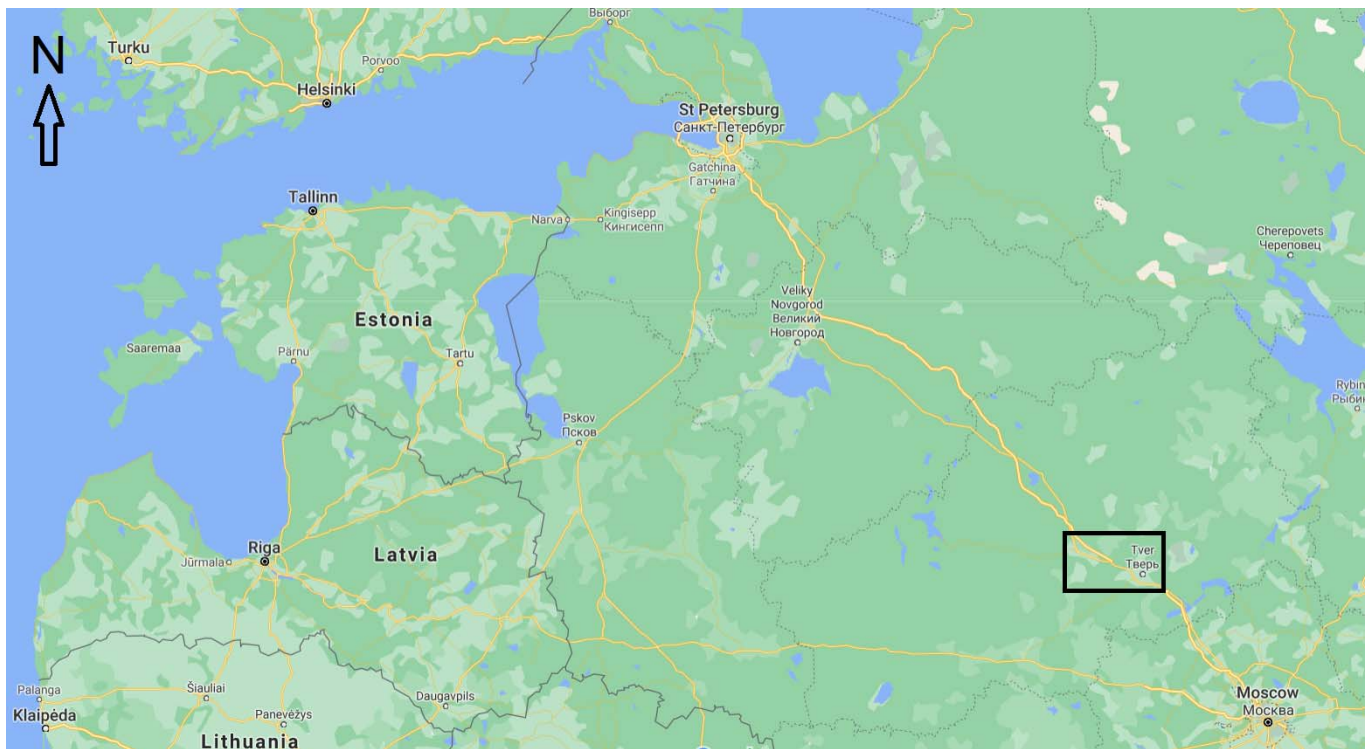
In 2016, we conducted a field survey and examined ash trees (both *Fraxinus pennsylvanica* [dominant] and *F. excelsior*) planted along the federal highway M10 (Russia) that runs between Moscow and Saint Petersburg through Tver' City. The survey clearly demonstrated that the north-western limit of the European invasive continuous range of *A. planipennis* at that time was close to Tver' City [8]. Yet already in 2018, EAB was recorded within the limits of Tver' City [9,10]. The objective of the present study was to further monitor the north-westward expansion of the invasive European range limit of *A. planipennis*.

2. Materials and Methods

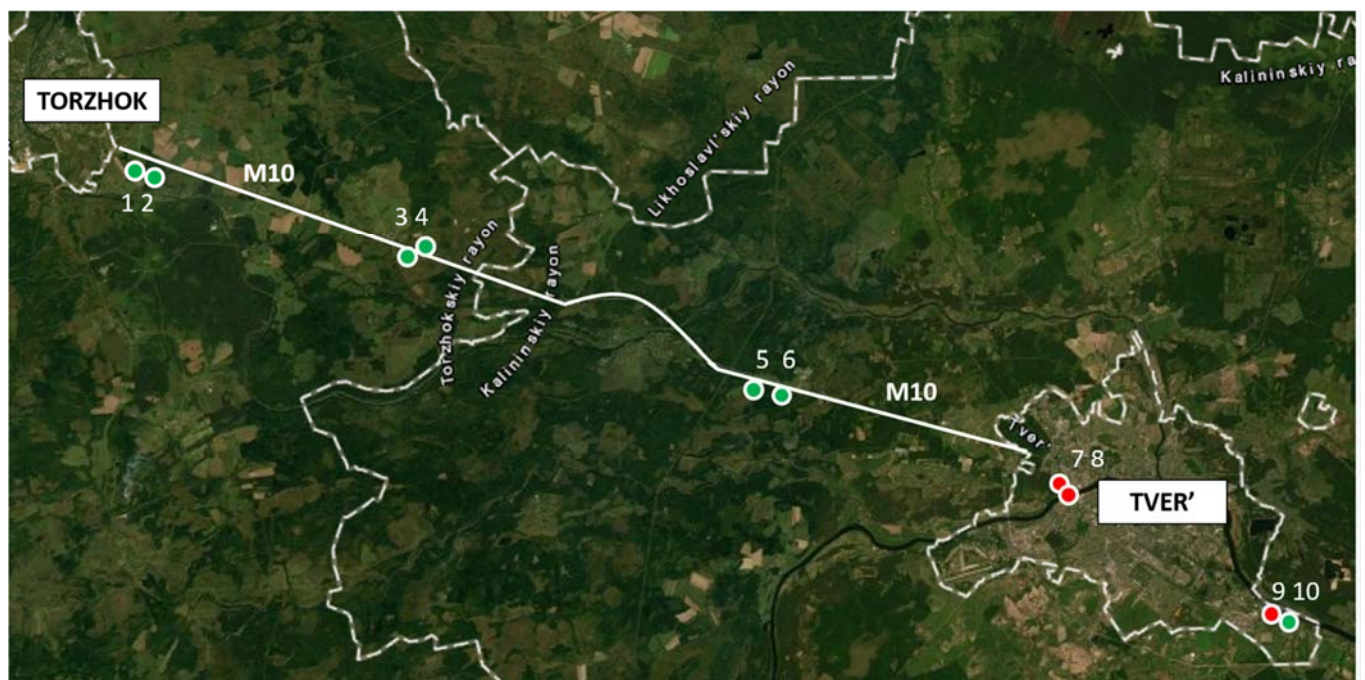
As in the survey of 2016 [8], we considered the federal highway M10 (Russia) that stretches between Moscow and Saint Petersburg through Tver' City and is lined with ash trees, which makes it the most probable route of EAB range expansion in the north-western direction from the Moscow Province as a center of the pest's secondary range in Eurasia. Through much of this highway, it is lined mostly with *F. pennsylvanica* (in some cases also with *F. excelsior*). To monitor and record the shift of the range's north-western limit in a timely manner, on 2–4 June 2018 we established 10 study plots (Figure 1a,b). On each plot, 2–4 *F. pennsylvanica* trees with height ranging 6.1–17.0 m and diameter at the breast height ranging 7.0–18.0 cm were chosen. These trees were girdled, i.e., 50 cm of their bark were removed at the height of 1.0–1.5 m (Figure 2a). In total, 24 trees were used (Table 1).

On each tree, two sticky trapping sheets were attached just above the section of removed bark (Figure 2b):

(1) 35 cm × 60 cm purple sticky trapping sheets made of colored corrugated plastic, routinely used for monitoring in the USA and Canada in prism traps [11,12] (Synergy Semiochemicals, Burnaby, BC, Canada; Figure 2b above), and (2) 14 cm-wide dark-green sticky belts commercially available under the trade name "Aerixon sticky belts" [<https://market.yandex.ru/product--kleikii-poiias-aerixon-dlia-derevev-3-5-m/233726103>] (accessed on 19 March 2021; Aerixon Insect Control GmbH, Hamburg, Germany; purchased in Russia; Figure 2b below).



(a)



(b)

Figure 1. (a) Location of the study area in the European part of Russia; (b) location of 10 study plots (numbered) along the federal highway M10 (Russia) that runs between Moscow and Saint Petersburg through TVER' and TORZHOK. The study plots where *A. planipennis* was recorded at least once on at least one tree are colored in red (# 7–9; see Table 1 for details). Maps are based on images from (C) Google, 2021.



Figure 2. (a) A girdled *F. pennsylvanica* tree (50 cm of the bark removed at the height of 1.0–1.5 m); (b) two sticky trapping sheets attached above the section of the removed bark: below—a 14 cm-wide dark-green sticky belt; above—a 35 cm × 60 cm purple sticky prism trapping sheets made of colored corrugated plastic. Photo by D. L. Musolin.

Table 1. Locations of the study plots, characteristics of girdled *Fraxinus pennsylvanica* trees, and results of regular examinations (September 2018–October 2019).

No.	Location	No. of Trees	Tree ID	Height, m	DBH, cm	Infestation by <i>Agrilus planipennis</i> (EAB): – Absent; + Present			Remarks
						Sept. 2018	Nov. 2018	Oct. 2019	
1	57.014492° N 35.078181° E	2	1A	6.8	10.0	–	–*		
			1B	6.1	9.5	–	–	–*	Galleries of <i>Hylesinus varius</i>
2	57.014307° N 35.079104° E	4	2A	8.5	10.5	–	–*		
			2B	7.4	10.0	–	–	–*	
			2C	9.5	11.0	–	–	–	Tree not cut
			2D	10.1	12.5	–	–	–	Tree not cut
3	56.97493° N 35.27902° E	3	3A	6.7	14.0	–	–	–*	Attempts of infestation by <i>H. varius</i>
			3B	6.5	10.2	–	–*		Attempts of infestation by bark beetles
			3C	11.3	18.0	–	–	–*	

Table 1. Cont.

No.	Location	No. of Trees	Tree ID	Height, m	DBH, cm	Infestation by <i>Agrilus planipennis</i> (EAB): – Absent; + Present			Remarks
						Sept. 2018	Nov. 2018	Oct. 2019	
4	56.912685° N 35.597971° E	2	4A	9.7	13.8	–	–	–*	
			4B	6.7	8.0	–	–*		
5	56.912583° N 35.598917° E	3	5A	6.5	10.0	–	–*		
			5B	7.5	10.8	–	–	–*	
			5C	6.5	8.0	–	–	–*	
6	56.909711° N 35.618255° E	2	6A	15.0	18.0	–	–*		Galleries of <i>H.varius</i> and <i>Trypodendron</i> sp.
			6B	9.3	10.0	–	–	–*	
7	56.867150° N 35.838599° E	2	7A	11.3	15.0	–	+*		Galleries and larvae of EAB
			7B	11.1	15.0	+	+	+*	
8	56.866971° N 35.838916° E	2	8A	10.2	17.0	–	+*		Galleries of EAB and <i>H.varius</i>
			8B	9.0	7.0	–	–	–*	
9	56.805391° N 36.025570° E	2	9A	17.0	14.5	–	+*		Old galleries of EAB; galleries of <i>H.varius</i>
			9B	11.8	14.0	–	–	–*	
10	56.805338° N 36.027415° E	2	10A	10.2	10.0	–*			
			10B	11.0	10.5	–	–	–*	

* Following observations of a standing tree, a tree was felled down for detailed examination.



Figure 3. An adult of *A. planipennis* (circled) glued to the dark-green sticky belt and collected on 18 July 2018 among other glued insects. Photo by E. Y. Peregudova.

It is believed that the girdling strongly attracts flying *A. planipennis* if the species is present in the location. Sticky trapping sheets were believed to further attract beetles (visually) and catch them due to the glue used [12].

There was no special reason for use of different types and colors of sticky trapping sheets. Initially it was planned to use only a “purple” type that is routinely used in the USA. However, subsequently, idea evolved to make a simultaneous pilot check for a “dark-green” type that is commercially available in Russia.

We utilized two patterns of placement of sticky trapping sheets on the ash trunks after girdling: trees with A and C in their ID numbers (e.g., 1A, 2A, 2C) had purple trapping sheets placed above dark-green sticky belts (Figure 2b; 13 trees in total), whereas trees with B and D in their ID numbers (e.g., 1B, 2B, 2D) had dark-green sticky belts placed above purple trapping sheets (11 trees in total).

The study plots with girdled trees were visited and the trees were examined three times after the initial establishment of the plots: on 23–24 September 2018; 16–17 November 2018, and 29–30 October 2019. During each visit to a study plot, sticky trapping sheets were carefully examined and the presence of *A. planipennis* adults recorded. Following the final observation (for individual trees it took place either during the 1st, 2nd or 3rd visit), twenty-two out of twenty-four trees investigated were cut (except for trees 2C and 2D; Table 1), measured and carefully examined focusing on any beetle’s exit holes on the tree trunk and branches. The bark was removed from several sections along the trunk up to the crown tip and along major branches in order to reveal any galleries of buprestids and/or bark beetles. In total, 22 trees were cut and fully examined. Additionally, trees located within Tver’ City were visited and observed on 18 July 2018 by E. Y. Peregudova.

3. Results

Three rounds of observations of the girdled ash trees, albeit during a limited period of time, revealed the following:

- (1) within Tver' City *A. planipennis* was recorded in both south-eastern (study plots # 9 and 10; 1 of 4 trees infested) and north-western (study plots # 7 and 8; 3 of 4 trees infested) parts;
- (2) the current continuous (in geographic sense, spatially uninterrupted) north-western limit of *A. planipennis* range in European Russia likely coincides with the north-western border of Tver' City;
- (3) this continuous range limit has not distinctly shifted north-westward during the last 4 years (since at least 2015);
- (4) in spite of the rich food supply (mostly *F. pennsylvanica*, but also *F. excelsior* are widely planted in parks and boulevards of Tver' City and along roads going to and from the city in different directions), the population density of *A. planipennis* is currently low in Tver' City, as only one adult was caught by the dark-green sticky belt placed above a purple trapping sheet (tree # 7B; recorded on July 18, 2018) during the whole monitoring period;
- (5) it turned out to be impossible to conclude whether dark-green or purple sticky trapping sheets are more effective, as only one *A. planipennis* adult was collected;
- (6) *Hylesinus varius* (Fabricius, 1775) (Coleoptera: Curculionidae) was recorded on numerous occasions on many trees that were cut and examined.

4. Discussion

Field observations presented in the current work strongly indicate that EAB did not (at least to a notable extent) spread further north-westwards from Tver' City, e.g., as rapidly as it could have been expected, if at all. In Tver' City, many ash trees are damaged by *A. planipennis*, but the damage caused is somewhat local or clustered and massive dieback of ash trees is not observed [10,13], (our unpublished observations). Thus, as the plantings of *F. pennsylvanica* and *F. excelsior* in Tver' City and along roads going to and from are abundant, forage reserve of *A. planipennis* in Tver' City is far from being exhausted. Even at our study plots # 7 and # 8, only 3 out of 4 girdled *F. pennsylvanica* were infested by the EAB. Further north-westward, ash trees are available only along the federal highway M10 (Russia) Moscow-Saint Petersburg that runs through Tver' City, where our study plots were located (Figure 1). However, even severely weakened girdled ash trees did not attract any *A. planipennis* adults outside Tver' City indicating that the north-west limit of the species' invasive range in this region did not shift during 2015–2019, thus remaining similar to that reported in our previous study [8]. However, one should keep in mind that our results are likely to reflect the minimal catch of the targeted EAB beetle. First, the glue might not remain sticky enough to catch properly after a certain time of exposure to rain, dust, sun, etc. Second, as the EAB is a strong flyer, several of them could have had escaped from the traps before inspections. And third, birds can peck up beetles from the sticky belts.

Nevertheless, recently (September 2020), a sudden outbreak of *A. planipennis* was unexpectedly recorded far north-westward—in Petrodvorets (Peterhof) district of Saint Petersburg, at the distance of approx. 520 km from Tver' City [14]. Our preliminary observations indicated that about 200 ash trees (approx. 90% of those *F. pennsylvanica* and 10% *F. excelsior*) have been infested and most of them were killed. Analysis of archived Yandex Panorama and Google Street View photographs suggested that EAB arrived at this location in the mid-2010s [15]. Keeping in mind that over the previous years EAB was intensively searched for in areas stretching from Tver' towards Saint Petersburg (ash hedges along the M10 (Russia) highway route were thoroughly investigated) without any record of the beetle beyond the limits of Tver' City [8,16–18], we believe that *A. planipennis* arrived at Saint Petersburg as a result of its accidental introduction by means of, e.g., “insect-hitchhiked” vehicles, transported plants for planting, and/or other commodities. Notably, EAB beetles can easily travel by cars being hidden behind flanges of the car body; the insect can stay even on a tree branch pressed by a wiper to a windshield at a car driving at speeds of up to 120 km/h [19]. Railway cars also often serve as substrates for traveling

beetles [20]. As a result, in the suburb of Saint Petersburg *A. planipennis* has currently established, although relatively small, local, and geographically isolated, a nevertheless destructive population.

Both *F. pennsylvanica* and *F. excelsior* are well represented in parks and boulevards of Saint Petersburg and its numerous historical suburbs. Recent (October–December 2020) urgent inspection of parks in Pushkin, Pavlovsk, and Gatchina (all suburbs of Saint Petersburg) did not reveal any other foci of infestation of *A. planipennis* [our unpublished data]. Therefore, although it is not known as to when, where from, by which means, and what size of EAB population has been initially introduced to the Saint Petersburg region, yet it seems that, despite being locally destructive, the beetle has not conducted further spread over considerable local distances, and, at least to date, has remained confined within Petrodvorets, namely in the area of its apparent introduction and outbreak. Therefore, the patterns of local population dynamics of EAB (restricted local spread) currently observed in both Tver' and Saint Petersburg are to a certain extent similar, despite different arrival scenarios: to Tver' years ago by "natural means", namely by insects flying stepwise from tree-to-tree along highway hedges [8], whereas to Saint Petersburg due to sudden (yet more recent) point-to-point human-mediated introduction over apparently large geographic distance. Such restricted local spread by "natural means" (insect flying) at the given north-western geographical latitude could be associated with climatic conditions, high availability of food, and/or pressure of parasitoids.

Temperature has been reported to be a limiting factor of spread of *A. planipennis* [21] and references therein. Not surprisingly, therefore, notably more efficient rates of "natural" expansion have been observed of invasive European EAB populations approx. 1000 km south in eastern Ukraine (where movement of ash plant material following the invasion was forbidden); in June 2019 it was reported to be infesting ash in eastern Ukraine (Luhansk Region), about 25 km from the nearest known EAB locality in Russia [22], and already by September 2019 there were three new reports of EAB in Ukraine within 2 km radius from the initial observation point [23]. By summer 2020 *A. planipennis* has spread over 100 km westwards, entering Sumy Region [Dr. Kateryna Davydenko, personal communication]. This is not surprising, as, for example, in the Great Lakes region of North America, EAB adults were reported to be strong fliers capable of dispersal flights, gravid females estimated to fly more than 10 km in 24 h [24].

Even though Saint Petersburg is located approx. 520 km further north-westward than Tver', the climatic conditions are milder in Saint Petersburg than in Tver' (with a difference of the average temperature of approx. 2.0 °C) [25]. That is why it is possible that the current north-western limit of the continuous invasive range of *A. planipennis* lies close to Tver', but at the same time an isolated local population of the pest exists in Saint Petersburg. Easy availability of food resources, as well as pressure of natural enemies (first of all a parasitoid *Spathius polonicus* Niezabitowski (Hymenoptera: Braconidae: Doryctinae)), might also slow down the shift of the pests' north-western range limit.

It is evident that *A. planipennis* is currently approaching EU borders from the east covering a large geographical range, stretching over 1000 km from Saint Petersburg to eastern Ukraine. While the geographic distance from eastern Ukraine to the eastern EU is large, comprising approx. 800 km, one must keep in mind that the "natural" spread of EAB there is rapid and highly efficient, and that in Ukraine (and Belarus), *F. excelsior* and highly EAB-susceptible North American green ash (*F. pennsylvanica*) historically have been extensively planted along roads, railways, field shelter belts, and urban greenings. On the other hand, as suggested above, "natural" spread of EAB towards the EU from north-western Russia appears to be slow and limited, and long-distance spread here is mainly governed by human-mediated means, thus plant quarantine regulations to restrict further spread in such case are relevant.

But also in this case one should take into account the fact that woodlands of ash are common along the north-eastern Baltic coast, stretching from Saint Petersburg towards both Estonia (120 km) and Finland (130 km). These woodlands potentially provide an

excellent route pathway for EAB towards the European Union, especially in the context of ongoing global climate change. Moreover, during the last two decades the ongoing massive ash dieback has devastated over 95% of its European population [26]. The question remains open as to how much of it will remain following (inevitable) EAB invasion. In conclusion, the future of ash in Europe is under the threat.

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