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New Data on the Southeastern Border of the Invasive Range of *Agrilus planipennis* (Coleoptera: Buprestidae) in the European Part of Russia

A. N. Volodchenko*

Balashov Institute, Saratov State University, Balashov, Saratov oblast, 412300 Russia
**e-mail: kimixla@mail.ru*

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Abstract—The emerald ash borer *Agrilus planipennis*, which is native to East Asia, is a highly destructive pest of ash trees (*Fraxinus* sp.) in European Russia and North America. This quarantine species is currently spreading in the European part of Russia and in the east of Ukraine. The purpose of this study is to determine the distribution of the species in the southeast of the main part of the invasive range. The material was collected in Tambov, Voronezh, and Volgograd oblasts of the European part of Russia in 2021. The pest has spread to the central part of Tambov oblast, has almost completely populated Voronezh oblast, and has penetrated into the northwestern part of Volgograd oblast. Findings of *Agrilus planipennis* have shown that the invader continues to spread to the southeast of the European part of Russia. The border of the invasive range of *Agrilus planipennis* is already located in the immediate vicinity of the regions of the European part of Russia where the common ash is one of the main forest resources. Further expansion of the pest will cause significant ecological and economic damage.

Keywords: emerald ash borer, EAB, *Fraxinus* sp., alien species, invasive pest, range expansion, southeast of the European part of Russia

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INTRODUCTION

The emerald ash borer *Agrilus planipennis* Fairmaire, 1888 (Coleoptera: Buprestidae) is a highly destructive invasive pest that affect ash stands in Europe and North America (Herms and McCullough, 2014; Valenta et al., 2016). The native range of the species includes northeastern China, the Russian Far East, the Korean Peninsula, and the Japanese islands (Orlova-Bienkowskaja and Volkovitsh, 2018). To date, the invasive range in North America has spread to 35 US states and five Canadian provinces (Emerald Ash Borer..., 2021). In Europe, the emerald ash borer (EAB) is found in the European part of Russia and northeastern Ukraine (Drogvalenko et al., 2019; Orlova-Bienkowskaja et al., 2020; Meshkova et al., 2021; Volkovitsh et al., 2021; Orlova-Bienkowskaja and Bieńkowski, 2022). In Russia, the pest was first found in 2003 in Moscow; according to the data of dendrochronological analyses, the pest was introduced to the capital no later than 1992 (Baranchikov et al., 2016). By 2022, *A. planipennis* had spread many regions of the central part of European Russia, forming one large fragment of the secondary range and several enclaves (Vlasov, 2020; Orlova-Bienkowskaja et al., 2020; Volkovitsh et al., 2021; Orlova-Bienkowskaja and Bieńkowski, 2022).

The main damage is caused by larvae that chew long serpentine galleries through the phloem and cambium layers, which often leads to the death of trees owing to disruption of nutrient transport (Wang et al., 2010). Since the presence of the pest in the first 1–2 years after infection is hardly noticeable, and the symptoms of tree damage resemble other causes of tree oppression, it is difficult to identify newly emerging pest populations in a timely manner. Trees die off in 4–5 years after infestation, when the pest abundance is already high and a stable local population has formed (Herms and McCullough, 2014). Such features of the EAB biology make it difficult to timely identify the invader and to control it.

Previous studies have shown that all native and introduced European ash species are prone to *A. planipennis* invasion (Baranchikov et al., 2014). Ash trees are an important component of forest ecosystems and cultivated landscapes; therefore, the invasion of the EAB seriously affects their ecological structure and biodiversity and can also lead to significant costs to mitigate the economic and environmental consequences of the invasion (Baranchikov et al, 2008; Valenta et al., 2016; Semizer-Cuming et al., 2018; Volkovitsh et al., 2021). Particularly high damage from the pest development is expected in the south and

southeast of the European part of Russia, where natural and artificial stands of the common ash (*F. excelsior*) occupy the largest area (Musolin et al., 2017; Volodkina and Volodkin, 2020).

The distribution of *A. planipennis* in the east and southeast of European Russia is still poorly investigated (Orlova-Bienkowskaja et al., 2020; Volkovitsh et al., 2021). In Tambov oblast, the species was first discovered in 2013 in Michurinsk (Orlova-Bienkowskaja, 2013). However, there are no data on the subsequent dynamics of invasion in the region. Surveys of ash stands in Tambov in 2013 and 2019 found no traces of the EAB (Orlova-Bienkowskaja, 2013; Orlova-Bienkowskaja et al., 2020). Other areas of the region were not examined for the presence of the species.

In Voronezh oblast, the EAB was also first discovered in 2013 in Voronezh (Orlova-Bienkowskaja, 2013). In 2017, the EAB was recorded in the western regions of the oblast, and spread to the Anninsky district to the east (Baranchikov et al., 2017). In 2018, it was found in the center of the region in the Talovsky district (Baranchikov et al., 2018), but in 2019, it was recorded in the southern part of the oblast, in Kantemirovsky and Rossoshanskiy districts (Orlova-Bienkowskaja et al., 2020). Surveys of the same years in the northeastern part of the oblast (the towns of Borisoglebsk and Povorino) did not reveal the presence of EAB (Orlova-Bienkowskaja et al., 2020).

The first data on the occurrence of *A. planipennis* in Volgograd oblast were obtained during a survey of the green ash plantations in the vicinity of Volgograd in 2018 (Orlova-Bienkowskaja et al., 2020). Until 2021, EAB foci in the west of the region were not registered. Thus, data on the distribution of the species to the southeast of the region is incomplete.

Tracking the expansion of the range of this pest is still relevant owing to the highly destructive nature of the pest. The purpose of our study is to clarify the boundaries of the distribution of *Agrilus planipennis* on the southeastern border of the European range.

MATERIALS AND METHODS

The study was carried out from June to December 2021 on the territory of Tambov, Voronezh, and Volgograd oblasts outside the southeastern boundary of the emerald ash borer range, which, according to the published data, conditionally corresponded to the Michurinsk–Talovaya–Rossosh line (Orlova-Bienkowskaja, 2013; Baranchikov et al., 2017; Orlova-Bienkowskaja et al., 2020). The search for the pest was carried out mainly along the main highways passing in the latitudinal and meridional directions. The distance from the extreme northern and southern points was 260 km; the width of the surveyed strip from west to east varied from 35 to 120 km. In total, 38 localities were surveyed: 9 in Tambov oblast, 22 in Voronezh oblast, and 7 in Volgograd oblast (Fig. 1; Table 1).

Roadside forest belts, rural and urban plantations, and natural forests with the participation or dominance of two species of ash, the green ash (*Fraxinus pennsylvanica* Marsh.) and the common ash (*F. excelsior* L.) were examined. The green ash dominates in artificial plantations, while the common ash dominates in the forest fund.

The crown openness, the drying out of individual branches and tree tops, the presence of root shoots and water shoots, and pecking of larval galleries by insectivorous birds served as indirect signs of tree infection during remote examination (Wilson and Rebek, 2005; Volkovich and Mozolevskaya, 2014). The presence of any of these signs was a mark of a possible occurrence of *A. planipennis*. Its detection led to a detailed examination of the stands. During the survey, the trees were not cut down: the surface of the bark was examined for the presence of characteristic D-shaped flight holes of adults; the bark of individual trees was opened and examined for the presence of EAB larvae. The species affiliation of adults and larvae was determined according to the work of Volkovitsh et al. (2019). Data on the evidence of the presence of EAB are included in Table 1. Also, Table 1 presents data on the trees with bark pecking in the plantations as presumably inhabited by the emerald ash borer (as a separate category). However, the lack of direct evidence of the presence of a pest also requires confirmation of the absence of EAB.

RESULTS

Survey of Ash Trees in Tambov Oblast

Our surveys of ash trees in November–December 2021 revealed the presence of *A. planipennis* in the southwestern and central parts of Tambov oblast: the signs of the EAB were noted in Zherdeevsky, Tokarevsky, Tambov, and Rzhaksinsky districts. Significant damage caused by the EAB was noted in the village of Tsvetkovka (Zherdeevsky district), where 100% of the green ash trees were drying out and had flight holes of the EAB. Also, the pest was found in the vicinity of the settlements of Krasnosvobodnoe and Chicherino, located along the Russian federal route R22, the Caspian Highway. In the later locality, the affected trees displayed such signs of the EAB presence as drying of individual branches and the development of water shoots on the trunk, which indicates a significant disruption in the transport of nutrients. However, in Tambov and Rasskazovo, the trees were still alive; there were no signs of drying out and water shoots, although, bird pecks (at a height of at least 3 m) were recorded. Such pecks were found in more than half of the examined ash trees. No evidence of the EAB presence was found to the east of the Caspian Highway, on the section of the Rasskazovo–Rzhaksa–Uvarovo highway.

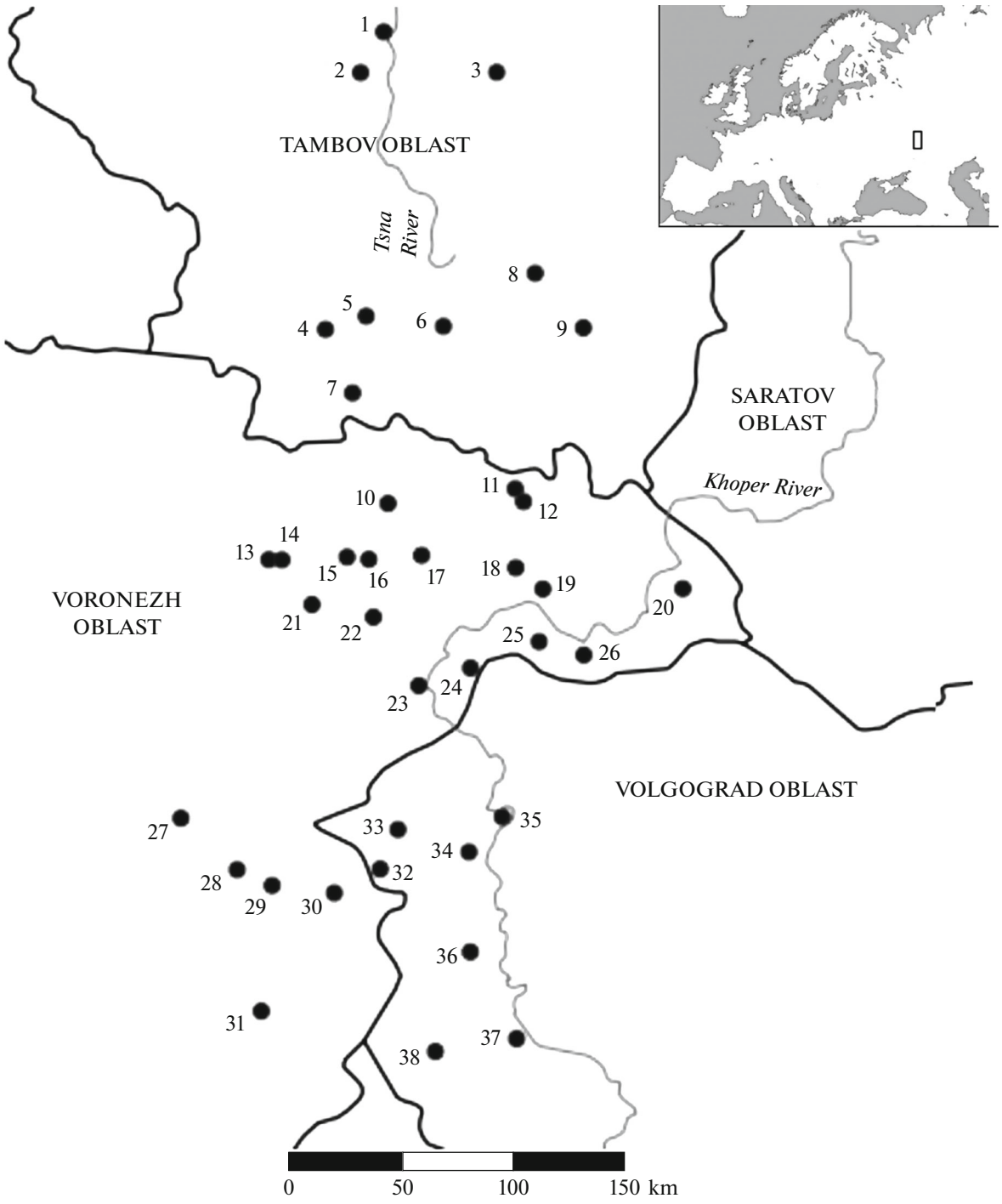

Fig. 1. Location of the material collection sites (the numbers of localities correspond to Table 1). The position of the study area on the map of Europe is given in the inset.

Survey of Ash Trees in Voronezh Oblast

Surveys in 2021 showed that the emerald ash borer was found in all areas of the northeast and east of the region. We first found it in Ternovsky, Gribanovsky, Povorinsky, Novokhopyorsky, Buturlinovsky, and Vorobyovsky districts and in Borisoglebsky urban district. Ash plantations to the west of the Bratka–Listopadovka–Troitskoe–Vasilevka–Vorobyovka line were damaged: the trees were oppressed or drying out, flight holes were noted on trunks at chest height and below, numerous larval passages indicated the abundant development of EAB larvae under the bark. The most heavily damaged ash trees were found in the roadside plantation in the vicinity of the village of

Table 1. Geographical coordinates and characteristics of forest stands in the surveyed localities

No.	Locality; coordinates	Forest stand	Ash species	Number of trees surveyed (Proportion of trees with signs of EAB colonization, %)	Signs of EAB colonization
			Tambov oblast		
1	c. Tambov; 52°44′11″ N, 41°26′27″ E	U	Fp	6 (0)	VI
2	v. Krasnosvobodnoe; 52°38′16″ N, 41°20′55″ E	P	Fp	20 (55)	II, VI
3	c. Rasskazovo; 52°38′19″ N, 41°53′27″ E	U	Fp	30 (0)	VI
4	v. Tokarevka; 52°0′39″ N, 41°12′32″ E	A	Fp	25 (0)	–
5	v. Chicherino; 52°2′36″ N, 41°22′15″ E	A	Fp	20 (80)	II, VI
6	v. Rakitino; 52°1′6″ N, 41°40′43″ E	A, P	Fp	20 (0)	VI
7	v. Tsvetkovka; 51°51′15″ N, 41°19′0″ E	A	Fp	20 (100)	I, II, VI
8	c. Rzhaksa; 52°8′55″ N, 42°2′39″ E	A	Fp	20 (0)	–
9	c. Uvarovo; 52°0′53″ N, 42°14′10″ E	U	Fp	20 (0)	–
			Voronezh oblast		
10	v. Bratki; 51°34′50″ N, 41°27′28″ E	A, P	Fp	25 (88)	I, II, VI
11	v. Aleksandrovka; 51°37′01″ N, 41°57′53″ E	A	Fp	20 (30)	II, VI
12	settl. Mezhevikhin; 51°35′07″ N, 41°59′52″ E	A	Fp	25 (0)	–
13	v. Arkhangelskoe; 51°26′27″ N, 40°58′59″ E	A	Fp	10 (100)	I, II, III, VI
14	settl. Kruglovskii; 51°26′25″ N 41°02′06″ E	P	Fp	30 (100)	I, II, VI
15	v. Novomakarovo; 51°26′50″ N, 41°17′41″ E	A, P	Fp	20 (100)	II, VI
16	v. Listopadovka; 51°26′30″ N, 41°22′53″ E	A	Fp	20 (30)	II, VI
17	v. Kalinovo; 51°27′06″ N, 41°35′30″ E	F	Fex	20 (0)	–
18	u-t set. Gribanovsky; 51°25′14″ N, 41°58′01″ E	F	Fex	25 (0)	–
19	c. Borisoglebsk; 51°22′04″ N, 42°04′29″ E	U	Fp	5 (40)	II, VI
20	v. Baichurovo; 51°22′07″ N, 42°37′57″ E	P	Fp	25 (0)	–
21	v. Yarki; 51°19′44″ N, 41°09′17″ E	A, P	Fp	20 (95)	I, II, VI
22	v. Troitskoe; 51°17′51″ N, 41°23′59″ E	A	Fp	40 (70)	I, II, VI

Table 1. (Contd.)

No.	Locality; coordinates	Forest stand	Ash species	Number of trees surveyed (Proportion of trees with signs of EAB colonization, %)	Signs of EAB colonization
23	c. Novokhopyorsk; 51°07′33″ N, 41°34′50″ E	U	Fp	12 (25)	II, VI
24	v. Bogdan; 51°10′13″ N, 41°47′12″ E	A	Fp	20 (0)	–
25	v. Oktyabrskoe; 51°14′10″ N, 42°03′36″ E	A	Fp	20 (20)	II, VI
26	c. Povorino; 51°12′10″ N, 42°14′17″ E	U	Fp	9 (0)	–
27	c. Buturlinovka; 50°47′32″ N, 40°37′57″ E	A, R	Fp	20 (100)	I, II, VI
28	settl. Pervomaysky; 50°39′43″ N, 40°51′24″ E	A, R	Fp	20 (100)	I, II, VI
29	v. Vorobyovka; 50°37′19″ N, 40°59′46″ E	A	Fp	20 (70)	II, VI
30	v. Krasnopolye; 50°36′11″ N, 41°14′38″ E	A, P	Fp	20 (55)	II, VI
31	v. Shiryaevo; 50°18′08″ N, 40°57′11″ E	A, P	Fp	10 (0)	–
		Volgograd oblast			
32	settl. Iskra; 50°39′49″ N, 41°25′36″ E	A	Fp	40 (2,5)	II
33	kh. Rozovskii; 50°45′49″ N, 41°29′51″ E	A	Fp	20 (0)	–
34	settl. Gornyi; 50°47′44″ N, 41°54′46″ E	A, F	Fex	15 (0)	–
35	kh. Rossoshinsky; 50°42′25″ N, 41°46′50″ E	A, P	Fp	40 (0)	–
36	st. Nekhaevskaya; 50°27′12″ N, 41°47′09″ E	A	Fp	20 (0)	–
37	kh. Denisovsky; 50°13′55″ N, 41°58′13″ E	F, P	Fex + Fp	30 (0)	–
38	kh. Kamensky; 50°11′57″ N, 41°38′47″ E	A	Fp	10 (0)	–

Types of settlements: c., city; settl., settlement; u-t set., urban-type settlement; v., village; st., stanitsa; kh., khutor. Types of plantings: U, urban plantations; A, road protective plantations; R, railway protective plantations; P, field-protective forest plantations; F, artificial and natural forests of the forest fund. Tree species: Fex, *F. excelsior*; Fp, *F. pennsylvanica*. Evidence of the EAB presence: I, flight openings of adults; II, larvae in galleries under the bark; III, dead trees with larval galleries; IV, pecking of the bark by birds; (–) no signs were found.

Arkhangelskoe (the westernmost surveyed locality on the Russian route R298). In this plantation, up to 90% of the trees died, and the rest of the trees were weakened and had a very sparse crown. There were numerous flight holes on tree trunks. Severe EAB-associated damage to ash was recorded in ash plantations along the Ramonye–Elan-Koleno–Buturlinovka highway. Also, many dying ash trees were noted along the section of the Buturlinovka–Pervomaysky railway, surrounded by a wide (up to 150 m) protective strip of the green ash.

Plantations of the green ash, located to the east of this line, were less damaged by the EAB: there were both healthy trees and weakened trees with water shoots; however, no dead trees killed by the pest were found. The proportion of trees infested with EAB was lower (30–70% of trees are affected); only larval feeding galleries were noted at chest height; there were no

flight holes. In the northeast of the region (the city of Povorino, the village of Tretyaki), no traces of tree damage by the EAB were found.

There were no traces of infestation of the common ash with the EAB in forests. The search for EAB in the Tellerman Forest and the Khopersky State Nature Reserve was unsuccessful.

Survey of Ash Trees in Volgograd Oblast

Our surveys in November 2021 revealed only single feeding galleries of the EAB larvae under the bark of ash trees near the village of Iskra, Uryupinsk district. The discovered site is located on the Buturlinovka–Uryupinsk highway, close to the border of Voronezh oblast. Examination of ash plantations located to the east along this route did not reveal any traces of tree infestation with the EAB. Also, no EAB colonies were found in plantations of *F. pennsylvanica* and forests with the participation of *F. excelsior* between the city of Uryupinsk and the stanitsa of Ust-Buzulukskaya. At the same time, some ash forest stands in this area (settlement of Gorny, Rossoshinskiy and Denisovskiy khutors) were strongly weakened and included dead trees, as well as trees with a sparse crown and drying branches. However, no signs of *A. planipennis* development and bird pecking were found there: only adults of the ash bark beetle (*Hylesinus varius* (Fabricius, 1775)) were found in the bark of weakened trees.

DISCUSSION

Our surveys showed that the invasive range of *A. planipennis* is actively expanding to the southeast. The EAB already has spread to the central regions of Tambov oblast, has almost completely populated the eastern regions of Voronezh oblast, and has begun its expansion to the western regions of Volgograd oblast. The easternmost finds of EAB in the Novokhopyorsky and Povorinsky districts (the village of Oktyabrskoye, the city of Novokhopyorsk, the villages of Pykhovka and Krasnopolye) are quite near the border of Volgograd oblast. Thus, it is highly possible that the pest will colonize the border ash plantations of the Uryupinsk and Nekhaevsky districts. Given the high adaptability of the species (Sobek et al., 2011; Orlova-Bienkowskaja and Bieńkowski, 2015, 2020), further rapid expansion of invasion into the southern and southeastern regions of the European part of Russia should be expected.

The understanding of the dynamics of the pest invasion process and the methods of its dispersal are of great importance. Possibly, the main pathways of *A. planipennis* spread from the center of the invasive range in Moscow are roadside forest belts of the green ash (Orlova-Bienkowskaja, 2013; Selikhovkin et al., 2017), along which the pest spreads independently or is unintentionally spread by humans. In the United States, the most likely way for human dispersal is considered to be the transport of EAB in the wood of dead ash trees (as timber or firewood) outside the infected areas (Solano et al., 2021) and, less often, infected young trees and seedlings (Siegert et al., 2015). However, the possibility of dispersal of adult insects on automobile (Back and Marshall, 2016; Gninenko et al., 2016) or rail transport (Short et al., 2020) has also been noted.

Considering the foregoing, we assume that, in the surveyed area, the EAB spreads both independently and with human assistance. Independent distribution of the species to the east of Voronezh oblast and further to Volgograd oblast is favored by the wide occurrence of green ash in the roadside and field-protective plantations, as well as its wide use in urban beautification. At the same time, individual ash forest belts often border each other and form an expansive network along roads and railways. In other cases, if forest belts are separated by small gaps, the adults of pests are able to overcome them on their own. In the surveyed part of Tambov oblast, ash plantations are much less common in comparison to Voronezh and Volgograd oblasts; ash plantations can be separated from each other by 5 or more kilometers. Therefore, passive redistribution via humans is of greater importance, and invasion can be of a focal nature. This is confirmed by the presence of ash plantations with no signs of EAB occurrence within the invasive range (village of Tokarevka). However, additional surveys are needed in the northwest and north of Tambov oblast to confirm our assumption about the ways of distribution of the pest.

The effects of *A. planipennis* distribution on the forests with significant participation of the common ash in the southeast of the range of the pest remain unclear. EAB was not found in the Tellerman forest or in the Khoper Nature Reserve. At the same time, field studies in various parts of the European range of EAB show that the pest can colonize the common ash (Orlova-Bienkowskaja, 2013; Meshkova et al., 2021; Volkovitsh et al., 2021), although the obtained data is not sufficient for forecasting and damage assessment. It is obvious that the number and dynamics of colonies of the invader species in forest stands with common ash will be affected by the state of the trees and the impact of entomophages. However, our data show the presence of weakened and drying ash stands in Voronezh and Volgograd oblasts associated with the activity of another invasive pest, the causative agent of infectious necrosis of ash branches, the ascomycete *Hymenoscyphus fraxineus* (Baranchikov et al., 2016; Musolin et al., 2017). The consequences of the combined impact of two dangerous invasive organisms on ash plantations will be much more severe.

CONCLUSIONS

Thus, the modern border of the EAB range extends to the central regions of Tambov oblast, the northeastern regions of Voronezh oblast, and northwestern

regions of Volgograd oblast. Probably, in 2–5 years, the EAB will penetrate the areas of the Middle Volga region and will spread in the southwestern regions of Penza oblast and western regions of Saratov oblast.

Further invasion of the pest can lead to catastrophic consequences for forest ecosystems with the participation of ash in protected areas that are already inside the invasive range (Tellerman Forest, Khoper Nature Reserve) or near its modern border (Voroninsky State Nature Reserve and Nizhnekhopersky and Ust-Medveditsky natural parks).

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The author declares that he has no conflicts of interest.

Statement of the welfare of animals. This article does not contain any studies involving animals performed by the author.

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