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Occurrence of the Invasive Bark Beetle *Phloeosinus aubei* on Common Juniper Trees in the Czech Republic

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Abstract: The small cypress bark beetle *Phloeosinus aubei* is considered an invasive pest in several central European countries, and we have determined its current distribution on common juniper trees (*Juniperus communis*) in the Czech Republic. The results indicated that *P. aubei* is widely distributed in the country but is more common in the east than in the west. The beetle was mainly detected on older, damaged trees and on stems with diameters > 3 cm. The apparently widespread and abundant populations of *P. aubei* could explain infestations of the beetle on *Thuja* spp. and *Juniperus* spp. in gardens (three confirmed cases during the last 10 years). We consider *P. aubei* to be a potential pest on older, naturally occurring *J. communis* in protected areas where its population density could increase on weakened and damaged trees. We suggest that *P. aubei* can be monitored via simple inspection of dying and dead *J. communis* trees in the field.

Keywords: scolytid; small cypress bark beetle; *Juniperus communis*; longitude; monitoring; biological invasions

1. Introduction

Bark beetles (Coleoptera: Curculionidae, Scolytinae) are among the most damaging pests of trees, because the adults and larvae tunnel beneath the bark; such tunnelling can eventually girdle and kill hosts. Most bark beetles breed in recently felled trees and especially in trees weakened by drought, defoliation by other insects, or diseases [1–3]. Many bark beetles are invasive and are easily transported with wood products, wooden packaging materials, nursery stock, and bonsai trees [4,5].

The small cypress bark beetle (sometimes referred to as the eastern juniper bark beetle or the cedar bark beetle) *Phloeosinus aubei* (Perris, 1855) (syn. *P. bicolor* Brullé) is a Mediterranean species that occurs mainly in northern Africa, the Near and Far East, and in southern Europe [6–11]. The main hosts of this phloeo- and xylophagous beetle are cypresses (*Cupressus* spp.), junipers (*Juniperus* spp.), and thujas (*Thuja* spp.) [9,12,13]. The number of generations per year ranges from two to four in the Mediterranean and Pontic areas [14–16], where the beetle overwinters as adults [14] and larvae [16] and begins to swarm when the temperature increases to 12 °C in the spring [15]. In Central Europe, in contrast, *P. aubei* has only one generation per year [17,18], overwinters mainly in the adult stage [18,19], and begins to swarm when temperatures exceed 20 °C [20]. In the Mediterranean area, *P. aubei* is an important pest, because it attacks and can kill host trees [21].

In the 1980s, the northern edge of the *P. aubei* range was in Central Europe, i.e., in northern Austria, southern Moravia (Czech Republic), southern Slovakia, and southwestern Hungary [7,9,17,22,23]. This invasive beetle was subsequently detected further north, i.e., in Brandenburg in 2001 [22,24], in the Netherlands in 2004 [25], in eastern Slovakia in 2007 [26], and in Poland in 2014 [20].

In Mediterranean countries, where *P. aubei* has been responsible for large areas of deforestation, its primary native host is the Italian cypress *Cupressus sempervirens* L., 1753 (Cupressaceae). The primary symptoms of infestation by this pest are dry branches or dry stems. The tunnelling activity of *P. aubei* in the woody parts of trees facilitates infection by the fungus that causes cypress canker, *Seiridium cardinale* (W.W. Wagener) B. Sutton & I.A.S. Gibson, 1972, and it is cypress canker that eventually kills the host [14,27]. As vectors, bark beetles primarily transfer ophiostomatoid fungi [28–30].

In addition to attacking forest trees, *P. aubei* can damage trees in gardens [20,25,31–34]. These cases mainly involved *Thuja* trees and other exotic species. The occurrence of *P. aubei* on the common juniper *Juniperus communis* L., 1753, which is native to Central Europe, has not been reported. Given the rapid spread of *P. aubei*, its effects on *J. communis* should be assessed.

Juniperus communis is of conservation concern in that part of its range where it is failing to regenerate [35], and is considered to be a "near-threatened" species in the Czech Republic [36]. Although *J. communis* is not threatened with extinction globally in any of its forms (subspecies or varieties) [37], the species is struggling to survive in those areas where changes in land-use and site management have reduced plant survival and recruitment [35].

Many *J. communis* populations are aging in the Czech Republic our study area, and this is thought to reduce reproductive vigor [38]. Moreover, diffuse pollution has been shown to interrupt pollination, fertilization, and embryo development [39]. Nitrogen deposition, sulphur deposition, and increased temperatures can have similar effects [40–43]. These factors, together with a wide array of non-bark beetle arthropods that attack *J. communis*, including the mite *Trisetacus quadrisetus* Thomas, 1889, and the chalcid wasp *Megastigmus bipunctatus* Swederus, 1795 [38,40], are weakening this highly valued tree species. Because *P. aubei* prefers weakened hosts, we hypothesized that its frequency of occurrence is increasing on *J. communis* in the Czech Republic.

The goals of the current study were to determine the distribution of *P. aubei* on *J. communis* in the Czech Republic, and to identify factors associated with its occurrence.

2. Materials and Methods

Field data were collected throughout the Czech Republic from January to October 2018 in 27 localities in protected areas and forests with >10% of one or more of the following *J. communis* habitats (Figure 1): T3.4A (broad-leaved dry grasslands with orchids and *J. communis*), T3.4B (broad-leaved dry grasslands with few or no orchids and with *J. communis*), T8.1A (dry lowland and colline heaths with *J. communis*), and T8.2A (secondary submontane and montane heaths with *J. communis*). The areas and forests with these habitats were selected based on the updated mapping of Natura 2000 [44] from the years 2007–2018. Each plot (one plot per locality) was surveyed only one time.

In each of the 27 plots, which ranged in area from 0.1 to 103.5 ha (habitat boundaries), we checked all *J. communis* trees with dry twigs (Figure 2). We debarked the trunk of such trees and checked the exposed wood and bark for galleries and beetles typical of *Phloeosinus* spp. The removed bark was 50 cm long on the vertical plane and included the entire circumference (Figure 2). Any bark beetles present were removed with tweezers, stored in alcohol, and identified to species by examination with a dissecting microscope (Bresser Advanced ICD Microscope 10x – 160x; Bresser GmbH, Rhede, Germany). The detection of a specimen of *P. aubei* was considered to indicate that *P. aubei* was present in the locality; the detection of galleries alone was not considered evidence of *P. aubei*. We also recorded the time required to detect the first *P. aubei* specimen (the 'finding time') in a plot; the finding time was considered an indicator of *P. aubei* abundance.

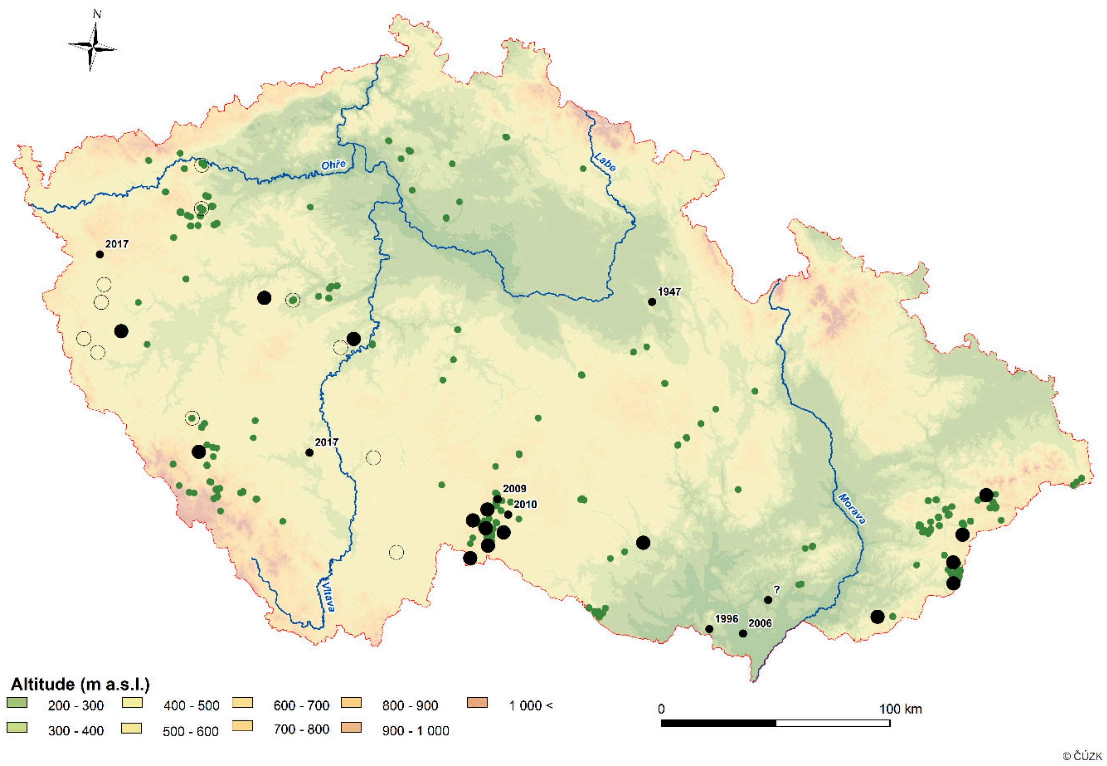

Figure 1. Occurrence of *Phloeosinus aubei* in the Czech Republic. Positive detections as documented in records before 2017 are indicated by small black circles (with detection year), and positive detections in 2018 are indicated by large black circles. Negative detections in 2018 are indicated by empty circles. Small green circles indicate juniper habitats (T3.4A, T3.4B, T8.1A, and T8.2A) according to Natura 2000 mapping in the Czech Republic (see Materials and Methods for details).

Figure 2. Dying junipers (*Juniperus communis*) in the Rajchéřov locality (**a**, the dying trees are red), galleries of *Phloeosinus aubei* on *J. communis* in the Mariánské Lázně locality (**b**), and a juniper tree damaged by antler rubbing in the Vrbička locality (**c**).

Data from private collections and museum collections were also summarized. Data from "Finding Database of Agency of Protection Nature and Landscape ČR" [45] are included as well as data from unpublished entomological reports.

The relationship between the presence/absence of *P. aubei* and longitude was analysed using a logistic model (Quassi-Newton method of estimation). Mann–Whitney U-tests were used to compare the following variables between localities with and without *P. aubei*: altitude, locality area, distance of the locality from the nearest *J. communis* locality, and population density of junipers. GLM analyses (Poisson distribution, LN link function) were used to determine the relationships between the 'finding time' and the locality characteristics indicated in the previous sentence plus locality management (managed vs. unmanaged). As noted earlier, finding time served as a surrogate measure of *P. aubei* population density. All tests were performed with Statistica 12.0 sofware (StatSoft CR, s.r.o.; Prague, Czech Republic).

3. Results

P. aubei was found in 16 of the 27 localities studied in 2018; the localities with *P. aubei* in 2018 were scattered throughout the Czech Republic and over a wide range of altitudes (160 to 720 m) (Figure 1). All localities with *P. aubei* in 2018 also contained *Phloeosinus thujae* (Perris, 1855). *Phloeosinus aubei* was found in all localities in the eastern part of the Czech Republic but in only about half of the localities in the western part of the country (Figure 3); this trend was statistically significant ($\chi^2 = 14.89$; $p < 0.001$). The habitats were also different in eastern vs. western parts of the country: protected areas were regularly maintained by grazing or cutting in the eastern localities but were overgrown with *Frangula alnus* Mill., 1768, *Prunus spinosa* L., 1753, *Rosa* spp., and other species in the western localities (Figure 4, Appendix A). The probability of *P. aubei* detection was not related to locality altitude ($z = 0.87$; $p > 0.05$), locality area ($z = 1.66$; $p > 0.10$), distance of the locality to the nearest juniper ($z = -0.30$; $p > 0.05$), or juniper population density in the locality ($z = 1.73$; $p > 0.10$) (Figure 5). Across all localities, the mean (±standard deviation) finding time was 14 (±16.6) min. Finding time was unrelated to locality altitude, locality area, distance of the locality to the nearest juniper, juniper population density in the locality, or locality management (F = 0.76; $p > 0.10$).

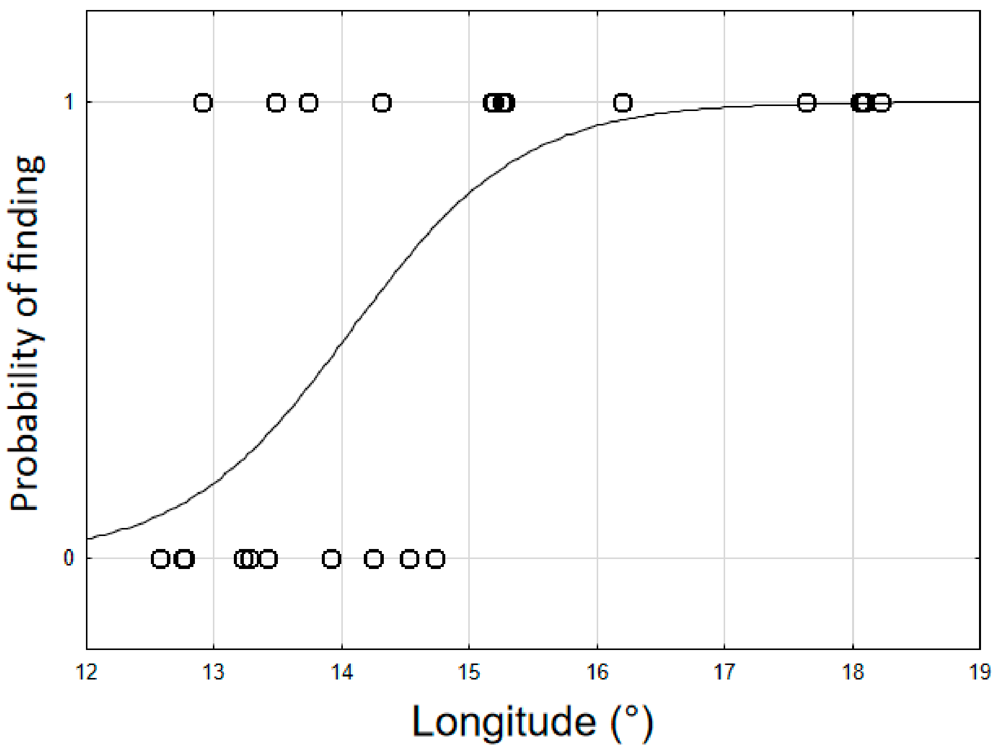

Figure 3. Logistic model for the probability of detecting *Phloeosinus aubei* in the Czech Republic as related to longitude. On the *y*-axis, 0 and 1 indicate that *P. aubei* was not detected or was detected, respectively.

Figure 4. Junipers overgrown by *Prunus spinosa* and *Rosa* spp. (**a**), and a juniper habitat regularly maintained by grazing at the Vrbička locality (**b**).

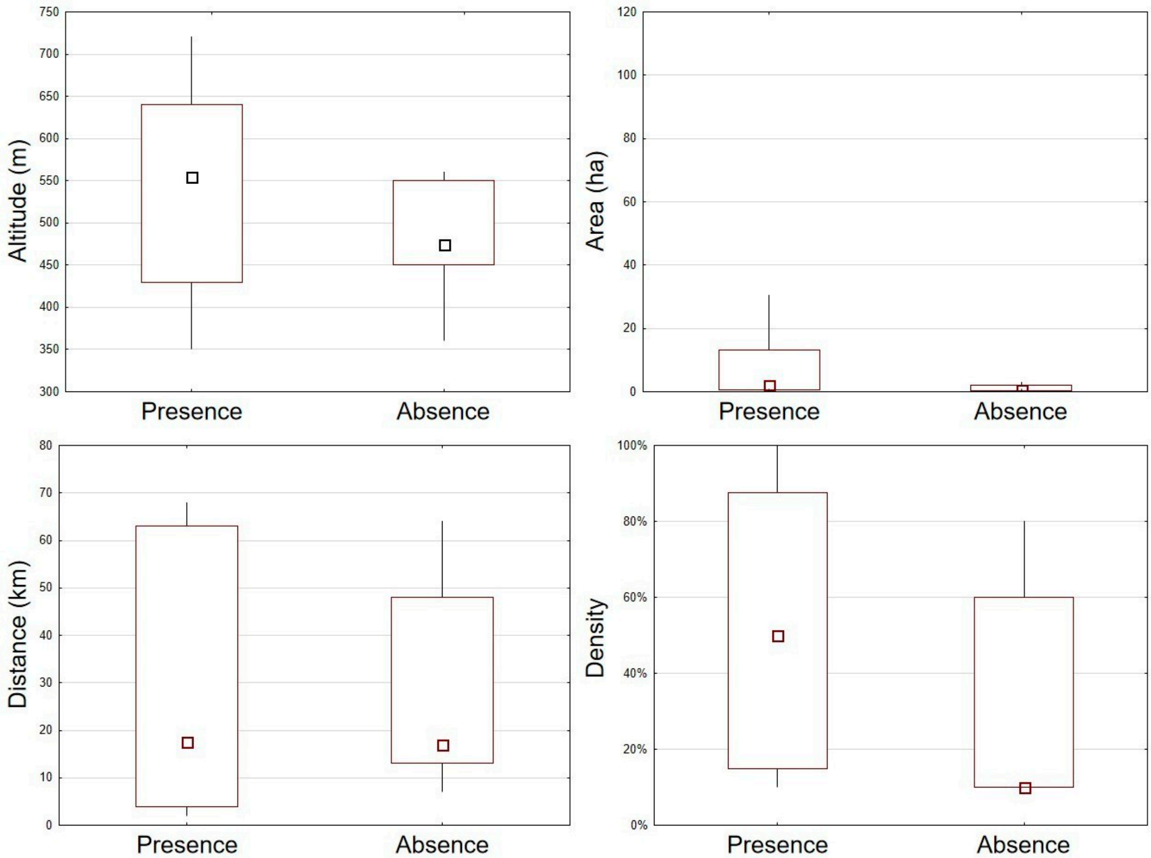

Figure 5. Relationships between the presence and absence of *Phloeosinus aubei* and the following characteristics of the localities: altitude, area, distance from the nearest juniper, and juniper population density. Small squares indicate medians, boxplots indicate the 25% and 75% quartiles, and lines indicate minimum and maximum values.

In addition to being found in 16 localities in 2018, *P. aubei* was previously found in 8 other localities (Figure 1). In all 24 localities where *P. aubei* has been detected, the host tree was usually *J. communis*, although the host tree was not indicated in some earlier reports and was *Thuja* spp. in one earlier report (Appendix A). Across all 24 localities, *P. aubei* was mainly found on *J. communis* stems thicker than 3 cm (Appendix A). In the one case in which *P. aubei* was found on *P. thujae*, the beetle was also found on branches thinner than 1 cm. In all localities where *P. aubei* was detected on *J. communis*, the trees had been damaged by cattle or game (Figure 2).

4. Discussion

The small cypress bark beetle *P. aubei* is native to the Caucasus, Asia Minor, and the Mediterranean area [6] from Israel [27] to southwest France [46]. Over the last 100 years or so, *P. aubei* has been spreading north from the Mediterranean area into Central Europe, where it has been reported as an alien pest [24,25,32,47–52].

The presence of *P. aubei* in the Czech Republic was first mentioned in the literature by Pfeffer [17], who referred to a single specimen captured by J. Picka. Although the details regarding that specimens are few, we do know that it was collected in the southeastern part of the country (i.e., in the historical country of Moravia) and probably in the village of Čejč. Its year of collection is unknown, but it was probably collected in the 1960s. The first dated finding of *P. aubei* in the Czech Republic was in 1947, and that specimen was found in the east-central part of the country (i.e., in the historical country of Bohemia) (current study). Previous studies had reported the detection of *P. thujae* [53,54] in the Czech Republic but not *P. aubei*. In the 1990s, *P. aubei* was reported from southern Moravia [55] and from Bohemia [56]; the latter report concerned outbreaks in several places in Prague and central Bohemia on *Juniperus* spp., *Chamaecyparis* spp., *Thuja* spp., and *Cupressus* x *leylandii* A.B. Jacks & Dallim., 1926.

In the Czech Republic, *P. aubei* has perhaps been spreading west (Figure 1), because *P. aubei* detection decreased from east to west (Figure 3). All studied variables (altitude, locality area, distance of the locality to the nearest juniper, and juniper population density) had large ranges in values in localities with and without *P. aubei* occurrence (Figure 5). Accordingly, these variables cannot be used to predict where the beetle will spread to, and only the presence of host trees appears to be important. A strong influence of host is typical for bark beetles [57]. That *P. aubei* is able to detect its host is confirmed by the fact that the 'finding time' was unrelated to host variables (area, distance of the nearest juniper, and density). *Phloeosinus* bark beetles have strong dispersal capabilities and can fly over 24 km [58,59]. The abilities to disperse and to detect hosts promote the spread of invading populations in a landscape matrix [60].

The increased spread of *P. aubei* in the Czech Republic corresponds with recent findings of increased spread of *P. aubei* in Germany [22,24], the Netherlands [25], and Poland [20]. This increase in *P. aubei* spread is probably a result of climate change [61–65] and increases in global trade [66–71].

The severe drought of 2003 possibly increased the susceptibility of juniper trees in Central Europe to bark beetles. For Western Europe, climate change models predict increasing summer drought and heat waves, which will increase the susceptibility of trees to secondary insect pests such as *Phloeosinus* spp. [25,72]. The finding of *P. aubei* in 1996 in the United Kingdom can be attributed to global trade, because *P. aubei* was found on *Thuja* spp. imported from Italy [52].

The main host of *P. aubei* in the Czech Republic is the common juniper, *J. communis*, which is listed in the ICUN Red List as near-threatened in the country [36]. Given the fragmented and small populations of *J. communis* (see Figure 1), gene flow is probably limited, with potential implications for the tree's long-term fitness and survival even where viable seed production occurs [73–75]. In such places, *P. aubei* can be considered a threat to the tree. This beetle kills *J. communis* trees that are weakened by drought or damaged by cattle grazing or antler rubbing by game [76,77]. Older stands of *J. communis* in the Czech Republic are in poor condition, and in many places they are overgrown (Figure 4). Factors that weaken the trees increase the spread of *P. aubei* and *P. thujae*, but precise quantification of both beetles is difficult because their galleries are very similar.

The frequent occurrence of *P. aubei* in many regions of the Czech Republic could lead to attack on thujas and junipers in ornamental gardens and cities, as has already occurred in the towns of Písek and Mariánské Lázně (Appendix A) and in Prague and other places in central Bohemia [56]. In contrast to *P. aubei*, *P. thujae* has not been reported on thujas and junipers in ornamental gardens and cities. In addition, *P. aubei* is a vector of pathogens and especially of the causal agent of cypress canker, *S. cardinale* ([18,51,78].

The monitoring of invasive bark beetle is necessary [79]. The use of pheromone trapping for monitoring *P. aubei* is not currently possible, because *P. aubei* pheromones have yet to be identified [23]. At present, *P. aubei* populations can be monitored by the debarking of symptomatic juniper and thuja trees in the field. Such field monitoring can be conducted throughout the year, because *P. aubei* adults and larvae are present under the bark throughout the year [19,34].

Expansion of either the true range or the outbreak range is observed in several model species/groups of major insect guilds in boreal and temperate biomes. Effects of climate change on forest insects are demonstrated for a number of species and guilds, although generalizations of results available so far are difficult because of species-specific responses to climate change. There is evidence that recent warmer temperatures have permitted the expansion of bark beetle outbreaks to higher latitudes and elevations than in the past [80].

Climate and weather can have direct effects on trees, as drought and storms can weaken trees and predispose them to attack by bark beetles and pathogens. Climate can also have direct effects on insects as they are small poikilotherms with limited thermoregulation ability [81]. *P. aubei* is a typical case of this pattern and may be followed by other species from Mediterranean countries. Climate change could also result in the spread of insect species from the opposite direction. *Ips duplicatus* (C.R. Sahlberg, 1836), a native bark beetle on Norway spruce in Scandinavia, currently is spreading to Central, Eastern, and Southern Europe. The outbreak is supported by the planting of spruce out of its original distribution, physiological weakness of the tree, and the consequent occurrence of fungal pathogens on host trees [82].

On the contrary, the spread direction of alien bark beetles in Europe could be different. Bark beetles mainly travel in wood and in wooden packing materials such as crating, dunnage, and pallets [83], so the places of introduction can be different. A North American species, *Gnathotrichus materiarius* (Fitch, 1858), and an East Asian species, *Xylosandrus germanus* (Blandford, 1894), currently occur in the Czech Republic, but they have been spreading from west to east from Germany [84].

5. Conclusions

The small cypress bark beetle has probably been present in the Czech Republic since the 1950s, and we have determined its current distribution on common juniper trees. The results indicate that *P. aubei* is widely distributed in the country but is more common in the east than in the west. The apparently widespread and abundant populations of *P. aubei* could explain infestations of the beetle on *Thuja* spp. and *Juniperus* spp. in gardens. We consider *P. aubei* to be a potential pest on older, naturally occurring *J. communis* in protected areas where its population density could increase on weakened and damaged trees.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Details of localities in the Czech Republic where *P. aubei* was detected in the current study (2018) and in earlier studies.

Locality	Coordinates	Year of Detection/ Collection	Source	Host Tree	Detail of Collections (Dimension of Trees and Management of Localities)
Čejč	48.9443903N, 16.9784694E	unknown	National Museum Prague	Unknown	collection of Jaroslav Picka
Drahoňův Újezd	49.8775892N, 13.7380344E	2018	T.Fiala	*Juniperus communis*	on 3-cm-d stems in a managed locality, 6 adults
Horní Jelení	50.0603294N, 16.0870206E	1947	V.Týr	Unknown	
Horní Němčí	48.9209667N, 17.6396400E	2018	T.Fiala	*J. communis*	on 5-cm-d stems in a managed locality, 3 adults
Horní Pole	49.2055956N, 15.2880703E	2018	L.Skořepa	*J. communis*	
Hutisko-Solanec	49.4359167N, 18.2234289E	2018	T.Fiala	*J. communis*	on 3-cm-d stems in a managed locality, 1 adult
Klatovec	49.2176503N, 15.3003911E	2009	[85]	*J. communis*	
Kunžak	49.1225056N, 15.1698425E	2009, 2018	[86], T.Fiala	*J. communis*	on 5-cm-d stems in an overgrown locality, 2 adults
Lednice	48.8028108N, 16.8508247E	2006	[45]	unknown	window trap on *Ulmus* spp.
Mariánské Lázně	49.9489864N, 12.7076350E	2017	T.Fiala	*J. communis*	on 4-cm-d stems of dead trees in a garden
Matějovec	49.0640136N, 15.2587572E	2018	L.Skořepa	*J. communis*	
Mikulov	48.8063058N, 16.6477686E	1996	[55]	unknown	
Mohelno	49.1153328N, 16.1991564E	2018	[45]	*J. communis*	
Nedašov	49.1015664N, 18.0897692E	2018	T.Fiala	*J. communis*	on 5-cm-d stems in a managed locality, 2 adults
Nový Svět	49.0820736N, 15.2574772E	2011,2018	[45], L.Skořepa	*J. communis*	
Odolenov	49.2413858N, 13.4837028E	2018	T.Fiala	*J. communis*	on 5-cm-d stems in a managed locality, 1 adult
Olší	49.1620167N, 15.3748231E	2010	[87]	*J. communis*	
Písek	49.3011936N, 14.1422844E	2017	D.Čudan	*Thuja* spp.	abundantly infested dead trees in a garden
Prostiboř	49.6638825N, 12.9095417E	2018	T.Fiala	*J. communis*	on 5-cm-d stems in a managed locality, 2 adults
Rajchéřov	48.9623267N, 15.1974642E	2009,2018	[88], T.Fiala	*J. communis*	on 3-cm-d stems in an overgrown locality, 1 adult
Valašské Klobouky	49.1395381N, 18.0633761E	2018	T.Fiala	*J. communis*	on 4-cm-d stems in a managed locality, 1 adult
Valtínov	49.0978514N, 15.2517989E	2009,2018	[89], T.Fiala	*J. communis*	on 3-cm-d stems in an overgrown locality, 2 adults
Záborná Lhota	49.7680669N, 14.3120808E	2018	T.Fiala	*J. communis*	on 3-cm-d stems in an overgrown locality, 5 adults
Zděchov	49.2726797N, 18.1021503E	2018	T.Fiala	*J. communis*	on 5-cm-d stems in a managed locality, 2 adults

Coordinates of localities without *P. aubei* occurrence: Bezděkov (49.7843667N, 12.7571769E), Doubravka (49.5852244N, 12.7634050E), Čečín (49.5915397N, 12.7508308E), Černýšovice (49.3151389N, 14.5270231E), Domanín (48.9584072N, 14.7393708E), Nechalov (49.7270689N, 14.2398522E), Vrbička (50.1882300N, 13.2770272E), Úhošť (50.3576158N, 13.2384503E), Ústí (49.8126472N, 12.7664183E), Zdebořice (49.3679767N, 13.4133169E), Žebrák (49.8847200N, 13.9121225E).

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