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ORIGINAL ARTICLE

Worldwide distribution and theoretical spreading of *Trichoferus campestris* (Coleoptera: Cerambycidae) depending on the main climatic elements

Sándor KESZTHELYI[1], Balázs FEHÉR[2] and Katalin SOMFALVI-TÓTH[1]

[1]*Department of Plant Production and Protection, Kaposvár University, Kaposvár, Hungary and* [2]*Hungarian Meteorological Service, Budapest, Hungary*

Abstract

The velvet longhorned beetle, *Trichoferus campestris* (Coleoptera: Cerambycidae) is a serious wood-boring pest that is a major threat to the phytosanitary condition of forests and orchards. Its worldwide expansion is a major concern for plant health. We have collected all bibliographical references, phytosanitary reports and authentic photographic evidence from entomological websites to determine the worldwide distribution of *T. campestris*. The theoretical directions of the spreading and actually occupied area of this arthropod pest were determined over the whole Holarctic range. Furthermore, the potential distribution area was calculated using cumulated temperature in the growing season averaged over 15 years both in the Palearctic and Nearctic regions. Holarctic expansion of the species, including the main parts of North America and Eurasia, is clearly indicated. Its populations occur in 29 countries to date, supported by documentation from 64 publications and 30 online forums. Its spread is continuously westward in the Palearctic; in the Nearctic, the spread was first southward from the Great Lakes region then eastward from Utah. The species has excellently adapted to circumstances of freight by ship and plane, as wood is often used, ensuring optimal conditions for the pest. In addition, the active spreading achieved by flying is an important factor contributing to its expansion. The primary criterion for controlling the species would be the introduction of a monitoring system in affected and exposed areas.

Key words: Cerambycidae, commercial and transport activity, ECMWF interim, global distribution, Holarctic range, temperature, *Trichoferus campestris*.

INTRODUCTION

The velvet longhorned beetle, *Trichoferus campestris* (Faldermann, 1835) (Coleoptera: Cerambycidae) is a serious wood-boring pest that is a major threat to the phytosanitary condition of wood products originating from forests and orchards (Allen & Humble 2002). Furthermore, the usability of wood packaging materials, timbers and pallets is endangered by its covertly developing larvae (Grebennikov *et al.* 2010). The pest is an A1 quarantine pest for Canada, and obtained the European and Mediterranean Plant Protection Organization (EPPO) A2 qualification, which called for its classification as a quarantine pest in 2007 (EPPO 2009). A US Department of Agriculture (USDA) risk assessment of *T. campestris* (Cavey 1998) concluded that the species presented a high risk to the USA, and it was recently added to the regulated pests' list of New Zealand.

The secret of its success lies in its good acclimatization ability to changed environmental conditions. The rapid, worldwide spread of *T. campestris* can be attributed to ever-growing commercial and urbanization activities. A survey of the USDA revealed that the increase in the number of first occurrences of invasive cerambycid beetles between 1985 and 2000 was mainly the result of an increase in the number of import items from China (Haack 2006), which is the native area of *T. campestris*. It is a typical secondary borer, doing no damage to living trees at all. Its further feature is a typical subcortical borer, and can infest only logs, boles

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Correspondence: Sándor Keszthelyi, Department of Plant Production and Protection, Kaposvár University, S. Guba str. 40, Kaposvár H-7400, Hungary.
Email: ostrinia@gmail.com

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and sawn timbers with bark attached. The species has a very peculiar trait, that it is highly resistant against the dryness of timber, and can infest indoor timbers (Iwata & Yamada 1990). Both the wide range of its host plants – including hardwoods and softwoods, and also some herbal materials – and its good flying skill have played important roles in the threat it poses. It has a wide range of host plants, approximately 40 genera of coniferous and deciduous trees (Cavey 1998), which makes it possible to find living conditions in diverse habitats. In addition, the invasiveness of the species is further strengthened by its vagility and good dispersion ability (EPPO 2009), namely adults capable of flying great distances at night. The natural spread of the species is unequivocally underscored by these latter facts.

Ontogenetic development of *T. campestris* depends on the cumulative temperature and on its distribution area. The pest overwinters as larva stage, inside sawn timbers. It comes from this that the life cycle of this beetle can take 2 or more years to complete. In Japan and Henan Province, China, *T. campestris* has a 1-year life cycle, whereas in the northern regions of Eurasia, the beetle develops over 2 years (Švácha & Danilevsky 1988).

The objective of this study was to map the worldwide distribution of *T. campestris* based on the processing of occurrences data of the species. Among our goals was the determination of the theoretical directions of its spread in different continents and to map the possible future distribution area of the pest based on climatological investigation on a 55.8 × 55.8 km grid in the Palearctic and Nearctic regions, as well as to determine the effects of climate change on the expansion of territory of the species.

MATERIALS AND METHODS

Mapping of the current distribution of *T. campestris*

We have collected all bibliographical references, phytosanitary reports and authentic photographic occurrences from entomological websites to determine the worldwide distribution of *T. campestris*. Several academic search engines (Google Scholar, Web of Science and Scopus) and international online insect forums (e.g. iNaturalist.org, flickriver.com, macroid.ru, macrogamta.lt, insects.nature4stock.com, insecta.pro and bugguide.net) provide primary help to the compilation of this extended database. First, the native distribution area was reconfigured based on the survey of Plavilshchikov (1940), in which the Western Palearctic region had formerly been indicated as a potential habitat of this serious pest. Each dataset was grouped by chronological order as well as the occurrence of places; circumstances and the present status of *T. campestris* was derived from them. In addition, theoretical directions of the spreading and actually occupied area of this arthropod pest were determined with the help of Dascălu *et al.*'s (2013) study and further observational records of beetles. Thus, we were able to prepare the global distribution of *T. campestris* over the whole Holarctic range.

Methodology of possible distribution based on climatic condition

In addition to the current spreading maps, the possible future distribution areas and the borderline of 1 and 2 years of development in the Holarctic were calculated using the threshold temperature for development (t_0 = 10°C), the accumulated day-degrees of *T. campestris* (C = 669 DD°) (A. Ray, pers. comm., 2018) as well as the cumulated temperature in the growing season of each possible location. The cumulated temperature in the growing season was calculated as $[T = \Sigma_n \times (t_{\text{aver.}} - t_0)]$; where: Σ_n = number of days in growing season, $t_{\text{aver.}}$ = daily average temperature. For the calculations of yearly development times (DT) $\{DT = [\Sigma_n \times (t_{\text{aver.}} - t_0)] / C\}$, adults' appearance in early April was taken into consideration after a short maturation feeding and copulation period (10 days). This calculation is based on the growing season (from 15 April to 30 November) uniformly, independent of examined areas and times. The abiotic data originated from the European Centre for Medium-Range Weather Forecasts (ECMWF) website (https://www.ecmwf.int), ERA-Interim Global Atmospheric Reanalysis dataset (Dee *et al.* 2011). These calculations were carried out using R open source software (R Development Core Team 2008).

From the ERA-Interim dataset, four temperature data (0, 6, 12 and 18 coordinated universal time) were used to calculate the daily mean temperature from 15 April to 30 November on 2,437 grid points in Palearctic and on 3,740 grid points in Nearctic regions. The distance between two grid points is 55.8 km. The northwestern corner of the Palearctic domain is N60°W11.25°, the southeastern corner is N39°E51°. The geographical parameters of the Nearctic domain are N60°W130.5° and N22.5°W75.75°. To avoid the interannual variability of habitats, the 15-year means of cumulated temperature were determined on both domains, as well as the change of habitats between 2003 and 2018 based on the annual number of grid points belonging to 1-year life cycles.

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Table 1 First observation data (year, circumstances) and presence status of *Trichoferus campestris* based on bibliographical data

	Country	Location	Year	Circumstances	Presence status	References
Asia						
1.	Kazakhstan	Almaty	<1973	Mentioned in literature	Present, no details	Kostin 1973
2.	Russia	Eastern Siberia				
3.	Armenia	–	<1985			Danilevsky & Miroshnikov 1985
4.	Iran	Bandar-e Anzali, Nastarud, Now Sar	2001	Reared from *Alnus* sp. and *Populus* sp. Hand-collected, attracted to the light	Present, several occurrences	Sama *et al.* 2005; Barimani *et al.* 2010
5.	Tajikistan	Dushanbe, Arykboshi, Tojikobod	2008	Hand-collected, attracted to the light		Danilevsky & Miroshnikov 1985; Kadyrov *et al.* 2016
6.	Kyrgyzstan	–	<2009	Mentioned in literature	Present, no details	EPPO 2009
7.	Turkmenistan	Kopet dag		Developed in orchards		Krivosheina & Tokgaev 1985
8.	Uzbekistan	—		Mentioned in literature		EPPO 2009
9.	Egypt	Sinai Peninsula			Presumed presence	Sabol 2009
10.	Israel	—				
11.	Jordan					
12.	Lebanon					
13.	Syria					
14.	Turkey	Ankara	2011	Reared from timber imported from Russia	Pest eradicated	Bozkurt *et al.* 2013
Europe						
15.	Russia	Rostov Oblast: Kamensk	1967	Mentioned in literature	Present, several occurrences	Kasatkin 2006
16.	Ukraine	Luhansk Oblast: Dyakove				Terekhova & Bartenev 2007
17.	Russia	Astrakhan Oblast: Astrakhan	1971			Danilevsky & Miroshnikov 1985
18.		Volg Oblast: Volgograd	1988			Kalyuzhnaya *et al.* 2000; Kasatkin 2006
19.	Ukraine	Kharkov Oblast: Kharkov, Donetsk	1989	Hand-collected, attracted to the light		Martynov & Pisarenko 2004; Terekhova & Bartenev 2007; Danilevsky 2017;
20.	Russia	Crimea: Evpatoria, Sevastopol	1992	Attracted to the light		Terekhova & Bartenev 2007; Zamoroka 2009; Bartenev 2009
21.		Chuvash Rep.: Morgaushkiy	2000	Mentioned in literature	Present, no details	Egorov 2005, 2006
22.		Mordovia Rep.: Saransk, Temnikov Dstr., Kovylkino Dstr., Ichalki Dstr.		Hand-collected, adults found in wooden buildings, wooded areas and wood pile	Present, several occurrences	Ruchin 2008, 2009; Semishin 2009; Ruchin & Egorov 2018
23.	Ukraine	Odessa Obl.: Odessa		Collected in evening on light		Terekhova & Bartenev 2007; Zamoroka & Korytnianska 2018
24.	Moldova	Kishinev, Chetrosu, Orhei, Micăuţi		Hand-collected		Chyubchik 2010; Dascălu *et al.* 2013
25.	Russia	Moscow Oblast: Moscow, Ivanovo	2002	Mentioned in literature	Present, no details	Danilevsky 2005, 2012, 2017
26.	France	Marseilles harbor		*Salix* sp. timber shipped from China	Pest eradicated	Cocquempot 2006
27.	Russia	Tula Oblast: Odoyev		Mentioned in literature	Present, no details	Nikitsky & Mamontov 2008
28.		Vor. Obl.: Voronezh				Tsurikov 2009; Danilevsky 2012
29.	Romania		2003			

(*Continues*)

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Table 1 Continued

Country	Location	Year	Circumstances	Presence status	References
	Constanta, Craiova, Bucuresti, Ivesti, Galati, Iasi		Hand-collected from wood pile and the wooden rafters of a house	Present, several occurrences	Dascălu & Serafim 2011; Dascălu *et al.* 2013; Orlova-Bienkowskaja 2017
30. Russia	Udmurt Rep.: Malaya Purga	2004	Mentioned in literature	Present, no details	Dedyukhin 2007
31.	Yarosl. Obl.: Yaroslavl	2006			Danilevsky 2012; Vlasov 2013
32. Czech Rep.	Otrokovice, Olomuc		Wooden pallets imported from Russia, adult came from *Gleditsia* sp.	Pest eradicated and moderated spreading	Sabol 2009
33. Slovakia	Sturovo, Šenkvice	2007	Collected on illuminated surface	Present, several occurrences	Sabol 2009; Majzlan & Vidlička 2016
34. Ukraine	Kryvets, Ivano-Frankivsk	2008	Attracted to the light		Zamoroka 2009; Zamoroka & Panin 2011; Zamoroka *et al.* 2012; Martynov & Nikulina 2016; Zamoroka & Korytnianska 2018
35. Hungary	Várpalota, Debrecen, Budapest, Kaposvár	2009	Collected by wine trap, attracted to the light, hand-collected from wood pile		Hegyessy & Kutasi 2010; Keszthelyi *et al.* 2017
36. Poland	Łasko, Dobiegniew		Hand-collected from mixed timber	Present, moderated spreading	Kruszelnicki 2010; Kurzawa 2017
37. Lithuania	Kaunas	2012	Caught using light trap		Ivinskis *et al.* 2014, 2015; Ferenca *et al.* 2016
38. Sweden	Lidhult		Reared from wood packaging material from China	Pest eradicated	Dascălu *et al.* 2013
39. UK	–	2013	Emerging from cutlery drawer imported from China		Eyre & Haack 2017
40. Austria			Several times in wood packaging material from China		EUROPHYT 2016; Krehan 2017
41. Italy	Naples	2015	Funnel traps located in the port		Pennacchio *et al.* 2016
42. Germany	Wilhelmshaven, Baden-Würtenberg	2016	In a residential building and several times in wood packaging material from China	Pest eradicated and moderated spreading	Julius-Kuehn Archive 2016; EPPO 2016; Bense 2017
North America					
43. USA	Florida: Leon	1992	Captured by light trap	Pest eradicated	Pfister & Valdez 2017
44.	New Jersey: New Brunswick, Middlesex, Burlington	1997	Detected in exterior of a high-risk warehouse site		Jackson *et al.* 2006
45. Canada	Quebec: Repentigny	2002	Hand-collected	Present, several occurrences	Grebennikov *et al.* 2010
46. USA	Washington: Seattle	<2006	From wooden dunnage in containers arriving from China	Pest eradicated	Pfister & Valdez 2017
47. Canada	British Columbia: Vancouver	2006			Grebennikov *et al.* 2010
48. USA	Rhode Island: Washington	2006	Mentioned in literature		Cook 2006
49. Canada	Ontario: Mississauga	2012	Reared from *Acer platanoides*	Present, several occurrences	Bullas-Appleton *et al.* 2013

(*Continues*)

Table 1 Continued

	Country	Location	Year	Circumstances	Presence status	References
50.	USA	Ohio: Hamilton, Franklin, Cuyahoga, Clermont	2009	Trapped by light trap and black intercept panel trap		Pfister & Valdez 2017
51.		Illinois: O'Hare Airport Crawford, Lake, DuPage, Cook, Kendall		Captured by funnel trap in commercial and industrial areas		Illinois Natural Resources 2012; Cook 2006
52.		Minnesota: Minneapolis, St. Paul Airport, Hennepin	2010	Captured in industrial area and at the international airport. Adults emerged from furniture		Minnesota Department of Agriculture 2018; Pfister & Valdez 2017
53.		Utah: Salt Lake City, Murray City		Hand-collected, trapped by funnel and cross vane panel traps		Burfitt *et al.* 2015; Watson *et al.* 2016
54.		Delaware: New Castle	2011	Captured by funnel trap and light trap in warehause. Could have emerged from pallet	Present, no details	Pfister & Valdez 2017
55.		Colorado: Larimer	2013	Captured by light and funnel traps		Watson *et al.* 2016; Pfister & Valdez 2017
56.		New York: Westchester	2014	Emerged from imported wooden furniture	Pest eradicated	Ray 2017
57.		California: San Diego		Live adult from willow planter	Present, no details	Pfister & Valdez 2017
58.		Pennsylvania: Allegheny, Carbon	2016	Trapped by *Trichoferus* lure trap		Pennsylvania Department of Agriculture 2016; Ray 2017
59.		Arkansas: Marshall		Emerged from furniture		Pfister & Valdez 2017
60.		Wisconsin: Milwaukee		Emerged from furniture and trapped by lure trap		Wisconsin Pest Bulletin 2017

–, No data.

RESULTS

Distribution and theoretical spreading of *T. campestris*

Table 1 includes the years of the first observations, the relevant circumstances and present pest status of *T. campestris* on the basis of bibliographical references. Linked to this collection, online reports are shown in Table 2, which completed this related database. Holarctic expansion, including the main parts of North America and Eurasia, of the species is clearly demonstrated, it can be found only on the Northern Hemisphere. Its presence has been documented in 29 countries (in 12 oblasts of Russia, 4 oblasts of Ukraine, 15 member states of USA and 3 provinces of Canada), which is supported to date by 64 publications and 30 online reports. Its spreading is continuously westward in the Palearctic; in Nearctic regions, the spread is southward from the Great Lakes and eastward from Utah.

The Eurasian expansion of *T. campestris* is shown in Figure 1. The determination of the exact native area of this pest is rather cumbersome. The Far East, including Mongolia, central and northeastern China and the Korean Peninsula comprised the original distribution area of *T. campestris*, as designated by several authors (Gressitt 1951; Cherepanov 1981; Tykarski *et al.* 2010). According to Fujita *et al.* (2018), this species has been a non-natural fauna element in Japan. Some researchers (EPPO 2008; Grebennikov *et al.* 2010; Dascălu *et al.* 2013) have also suggested Central Asian areas (Kazakhstan, Kyrgyzstan, Uzbekistan, Tadjikistan and eastern Russian up to the Ural Mountains) where the pest could be native. This latter statement could be controversial, because there are some references from these countries, in which the species was mentioned as a new fauna element or an unknown phytosanitary risk. These contested habitats are indicated by diagonal stripes in Figure 1.

The species has been observed in southern areas of the Caspian Sea, including Iran, from where according

Table 2 Incidence of *Trichoferus campestris* in online social networking sites and insect forums

	Country	Place of occurrence	Date	Photograph by	URL
61.	Canada	Toronto-Milverton	02.07.2018	oridgen10	https://www.inaturalist.org/observations/14002762
62.		Toronto-North York	20.07.2018	iabkarian	https://www.inaturalist.org/observations/14623209
63.	Georgia	Adjarien	31.08.2016	oskarlphansen	https://www.inaturalist.org/observations/4003424
64.	Hungary	Budapest	10.06.2013	T. Németh	http://www.nhmus.hu/ColeoColl/kepek/TRIPREPORTS/Reports/2013.VI.Budapest.html
65.		Bugyi	04.07.2016	F. Klecska	https://www.izeltlabuak.hu/faj/szallovendeg-ejicincer/kep/11047
66.		Budapest-Békásmegyer	27.06.2017	Zs. Újvári	https://www.izeltlabuak.hu/faj/szallovendeg-ejicincer/kep/24987
67.		Gyula	28.06.2017	Z. Nagy	https://www.izeltlabuak.hu/faj/szallovendeg-ejicincer/kep/10753
68.		Nádudvar	11.07.2017	S. Cseh	https://www.izeltlabuak.hu/faj/szallovendeg-ejicincer/kep/27276
69.		Százhalombatta	13.07.2017	D.Györe	https://www.izeltlabuak.hu/faj/szallovendeg-ejicincer/kep/11733
70.		–	09.07.2018	T. Németh	http://www.flickriver.com/photos/tags/trichoferus+campestris/interesting/
71.		Budakalász	22.07.2018	D. Kapitány	https://www.izeltlabuak.hu/faj/szallovendeg-ejicincer/kep/62675
72.		Szeged	22.07.2018	Cs. Hné Németh	https://www.izeltlabuak.hu/faj/szallovendeg-ejicincer/kep/55199
73.	Kazakhstan	Shymkent	23.06.2018	amirekul	https://www.inaturalist.org/observations/13763360
1.		Almaty	30.07.2018	kazenas	https://macroid.ru/showphoto.php?photo=183858&size=big&cat=19589
			14.08.2018	kazenas	https://macroid.ru/showphoto.php?photo=183860&size=big&cat=19589
37.	Lithuania	Kaunas	03.09.2018	R. Ferenca	http://www.macrogamta.lt/lt/coleoptera-vabalai/cerambycidae-ūsuotiniai/trichoferus-campestris-tamsusis-kamienvėris
74.	Netherlands	Venray	11.05.2012	L. Troisfontaine	https://en.m.wikipedia.org/wiki/Trichoferus campestris
75.	Romania	Iasi	19.08.2018	C. Manci	http://insects.nature4stock.com/?page_id=4067
76.	Russia	Ufa	11.06.2008	sergeygerasimo	https://www.inaturalist.org/observations/16232235
77.		Volgograd-El'shanka	12.06.2011	I. Pristian	http://insecta.pro/gallery/49900
78.		Volgograd	10.07.2011	E. Komarov	http://insecta.pro/gallery/44482
79.		Zheleznodorozhny	02.08.2012	V. Feoktistov	http://insecta.pro/gallery/43055
80.		Vostok	01.07.2014	M. Smirnov	https://www.zin.ru/Animalia/Coleoptera/rus/arhruseg.htm
81.		Moscow	16.07.2014	V. Feoktistov	http://insecta.pro/gallery/42890
82.		Gorodishchensky	16.07.2015	I. Pristian	http://insecta.pro/gallery/49914
83.		Begichevo	29.08.2015	Nakarb	https://www.inaturalist.org/observations/14566110

(*Continues*)

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Table 2 Continued

	Country	Place of occurrence	Date	Photograph by	URL
			13.01.2018	Nakarb	https://macroid.ru/showphoto.php?photo=179512&size=big&cat=19589
84.	Slovakia	Bratislava-Vrakuňa	30.07.2017	M. Everlingová	https://www.nahuby.sk/obrazok_detail.php?obrazok_id=630101
85.	South-Korea	Pocheon-si	20.04.2018	jaejinpark	https://www.inaturalist.org/observations/11190206
86.	Switzerland	Ettingen	–	O. Sebeseri	http://www.sebeseri.ch/tiere/trichoferus_campestris/index.html
87.	Ukraine	Kharkiv	29.06.2010	B. Loboda	http://ukrbin.com/show_image.php?imageid=28506
88.		Krivij Rih	26.07.2014	triungulin	https://macroid.ru/showphoto.php?photo=145531&size=big&cat=19589
89.		Odessa	27.04.2016	Nellie Sol	https://macroid.ru/showphoto.php?photo=157221&size=big&cat=19589
90.		Rostov	28.02.2018	B.G.Mot	https://macroid.ru/showphoto.php?photo=183860
91.	USA, Ohio	Montgomery	19.03.2018	J. Brown	https://bugguide.net/node/view/1501692

–, No data.

to Sabol (2009) it could have spread in a western direction to the Near East and Sinai Peninsula. However, these regions were not confirmed by other data. In all likelihood, the pest's direct intrusion into Europe can be delineated up to the south of the Ural Mountains, but it might also be through the Caucasus.

There are different hypotheses regarding its expansion in Eastern Europe (Fig. 2). *Trichoferus campestris* first occupied the areas north of the Black Sea. Some of the oldest European data originate from Crimea (1992), where *T.* c*ampestris* could have arrived through the Taman Peninsula or from the north, bypassing the Azov Sea. This latter hypothesis was proven by the earlier observation data from Terekhova and Bartenev (2007). To the north of European Russia, the pest spread probably along the Volga River and its side river Kama up to Malaya Purga (Udmurt). A large number of occurrences was reported in the steppe region of Russia, Yaroslavl. Interestingly, *T.* c*ampestris* was unknown from central and northern regions of Ukraine, and there are no data from forested Belorussia.

The westward spread of the species took two directions in approximately 2003–2008. It has advanced towards the Balkan Peninsula, thus reaching Odessa, Moldova, Wallachia and Dobruja. Additionally, it has rapidly spread along the northern range of the Carpathian Mountains. During this Central European thrust, *T. campestris* occupied north of the Carpathian basin, where its stable population have evolved. The species reached the north of Poland and the Baltic Sea, where it has spread moderately. Its presence, facilitated by imported goods, has already been verified in five European countries.

The conquest of the American continent has been accomplished through air and water trade by import items originating from China (Fig. 3). This is supported by several observations in commercial harbors of Seattle, Vancouver, Washington and Montréal as well as in the international airport of St. Paul and O'Hare Airport, Chicago. The northern areas of the Great Lakes can be assumed to be the primary source of further propagation in the Nearctic. From here, west- and southward active spreading has occurred to southern areas of Quebec and Ontario provinces in Canada and mid-east states of the USA (Minnesota, Illinois, Iowa, Ohio, Wisconsin and presumably Michigan and Indiana). This region (especially Illinois, Ohio and Minnesota) can be considered as primary sources of spreading habitat, where its stabile populations have been formed. Another, geographically separated state is Utah, where significant accumulation of *T. campestris* individuals can be found. In more regions of this state, the species was trapped by funnel and cross vane panel traps. It could spread eastward to Colorado from Utah (Watson *et al.* 2016). There are several records from distinct settlements (e.g. New Castle, Delaware; Marshall, Arkansas; San Diego, California) where it has spontaneously emerged from furniture or other wood materials.

Distribution as a function of climatic elements

Figure 4a shows the potential distribution area of *T. campestris* in the Palearctic region based on mean cumulated temperature between 2003 and 2018. The northern boundary of the 1-year life cycle area ranges

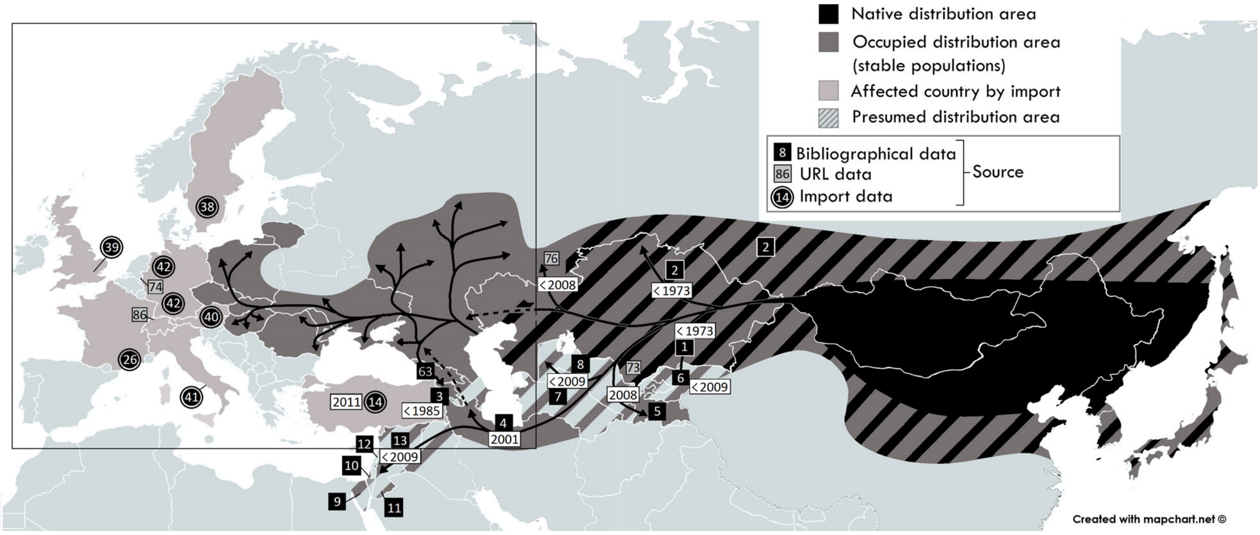

Figure 1 Occurrence data, distribution and the theoretical spreading of *Trichoferus campestris* in Eurasia.

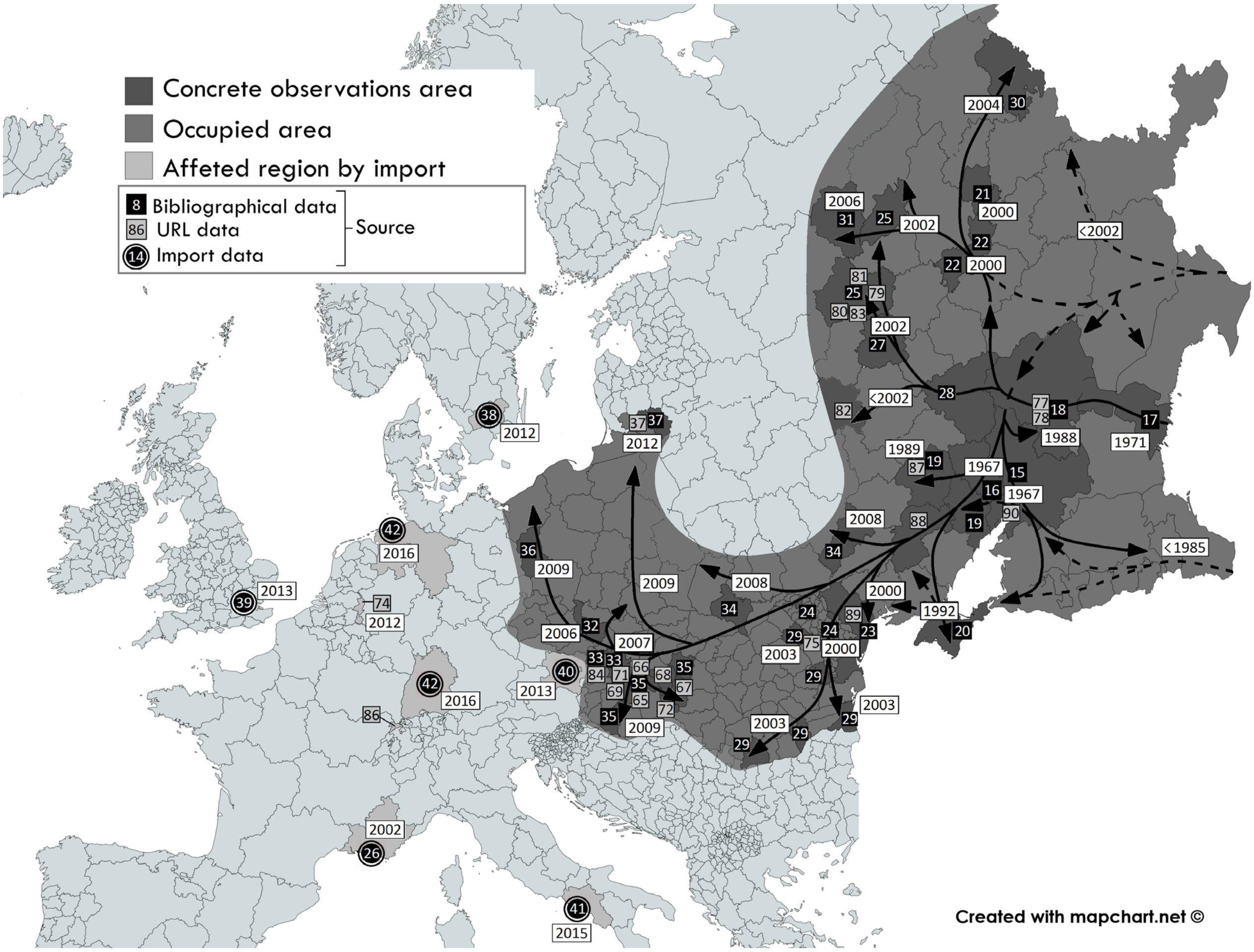

Figure 2 Occurrence data, distribution and the theoretical spreading of *Trichoferus campestris* in Europe.

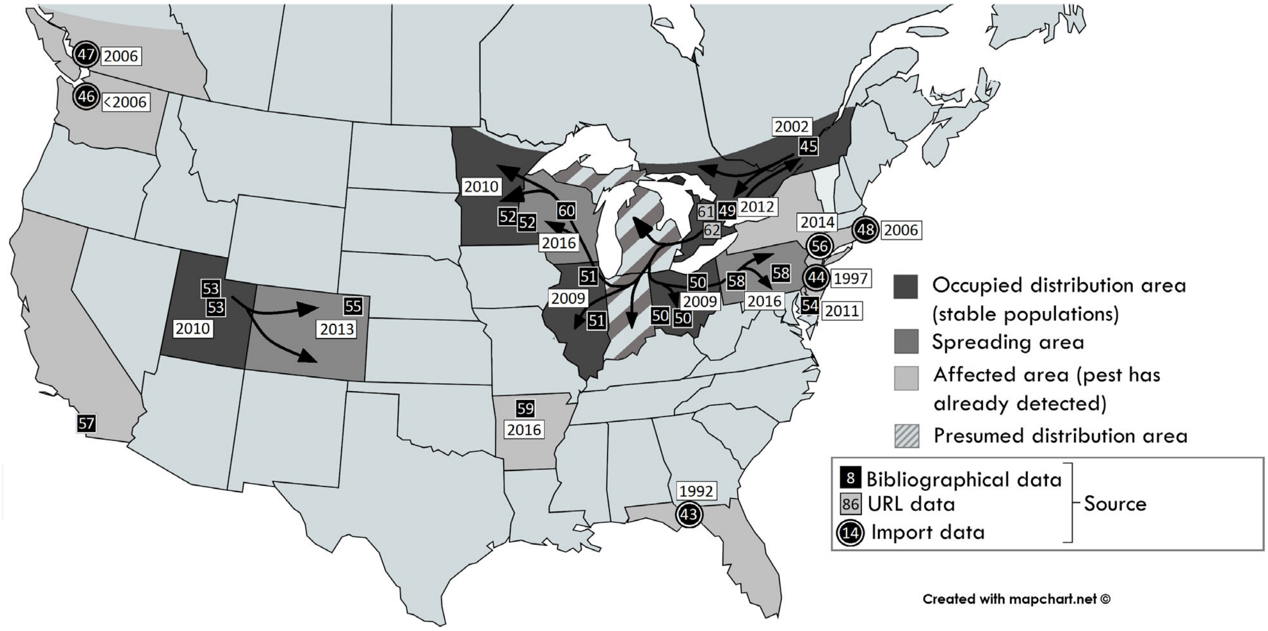

Figure 3 Occurrence data, distribution and the theoretical spreading of *Trichoferus campestris* in North-America.

from N52° to N54°. In warmer years (e.g. 2018) the border can move up to N55°, reaching the southern parts of Scotland or Sweden, while the expansion of the 2-year life cycle area narrows. This latter region forms a few hundred kilometer-wide band along N55°. Over N60° there are inadequate climatic conditions for the development of the beetle. Above 2,000 m a.s.l., in the Alps and the Caucasus, the thermal conditions are unfavorable for *T. campestris*. In the Nearctic region (Fig. 5a) the distribution pattern of different development cycles are similar to the Palearctic distribution. The transitional zone of the 2-year life cycle area is mostly narrower than in Europe, particularly near the Great Lakes. The Rocky Mountains' terrain above 2,000 m a.s.l. also falls outside the habitat.

The issue of climate change arises in connection with the possible poleward shift of habitat of *T. campestris*. Climate change has been shown to have accelerated in recent decades (Smith *et al.* 2015), in addition, the increase in temperature affects the Northern Hemisphere on a higher temperature degree (IPCC–AR5 2014). In order to determine changes in the latitudinal

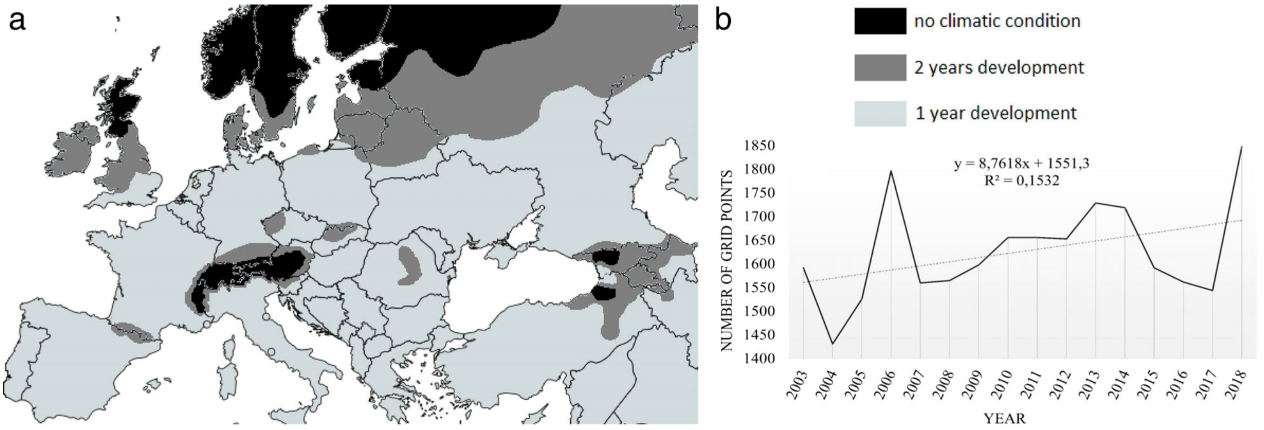

Figure 4 (a) Potential spread of *Trichoferus campestris* according to different ecotypes in Europe based on the European Centre for Medium-Range Weather Forecasts' ERA-Interim reanalysis, calculated by mean cumulated temperature, 2003–2018. (b) Number of grid points of the beetle's 1-year life cycle area, 2003–2018.

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range of the habitat of the beetle, the possible expansion area of *T. campestris* was studied in the last 15 years, based on temperature. The extension of the 1-year life cycle area has been increasing both in the Palearctic (Fig. 4b) and Nearctic regions (Fig. 5b) with a range of 0.32% and 0.18% per year, respectively, while the transitional zone of the 2-year life cycle area has been decreasing. However, there is significant interannual variability in temperature and so is in potentially exposed area, and the trend-like poleward shift of habitat cannot be detected during the studied period.

DISCUSSION

Rapid expansion of *T. campestris* in the Holarctic can be primarily explained with the intensifying commercial and other transport activities in the last decades (Grebennikov *et al.* 2010). The species has excellently adapted to circumstances of freight by ship and plane, because wood is often used, ensuring optimal conditions for the pest. In addition, the continuous increase in flights is an important factor for the fast expansion of the species (EPPO 2008). Both the wide range of potential hosts and global warming have been equally implicated (Dascălu *et al.* 2013).

Climate and weather can substantially influence the development and distribution of insects. Anthropogenically induced climatic change arising from increasing levels of atmospheric greenhouse gases would, therefore, be likely to have a significant effect on forestry insect pests. Such increase in temperature has a number of implications for temperature-dependent insect pests in mid-latitude regions (Chen *et al.* 2011; Smith *et al.* 2015). Naturally, *T. campestris* is no exception, because the increasing damage in timber industries can be unequivocally traced to the northward expansion of the 1-year life cycle ecotype of this species. The practical explanation of this ecological phenomenon is the increasing larval population numbers increasing the number of generations per year. In addition, further deterioration of wood quality in worldwide timber industry production will be induced. In a number of countries, phytosanitary risk analyses have been carried out due to the global threat posed by *T. campestris*, preparing for its potential appearance. According to Biosecurity Queensland (2014), Australia, the species poses a threat to a range of Australian timber industries. It can affect over 40 known plant hosts including mulberry, apple, pine, ash and willow trees in the case of a possible Australian appearance.

In 2013 in the UK, *T. campestris* was found to have emerged from a wooden cutlery tray imported from China (Eyre & Haack 2017). Therefore, the presence of this pest due to imported items is presumed in the foreseeable future, which is a great threat to broadleaved trees, particularly those in the south-west and south-east of England where climatic conditions could allow for a shorter lifecycle of the pest.

The primary criterion for protection against the species would be the elaboration of a monitoring system

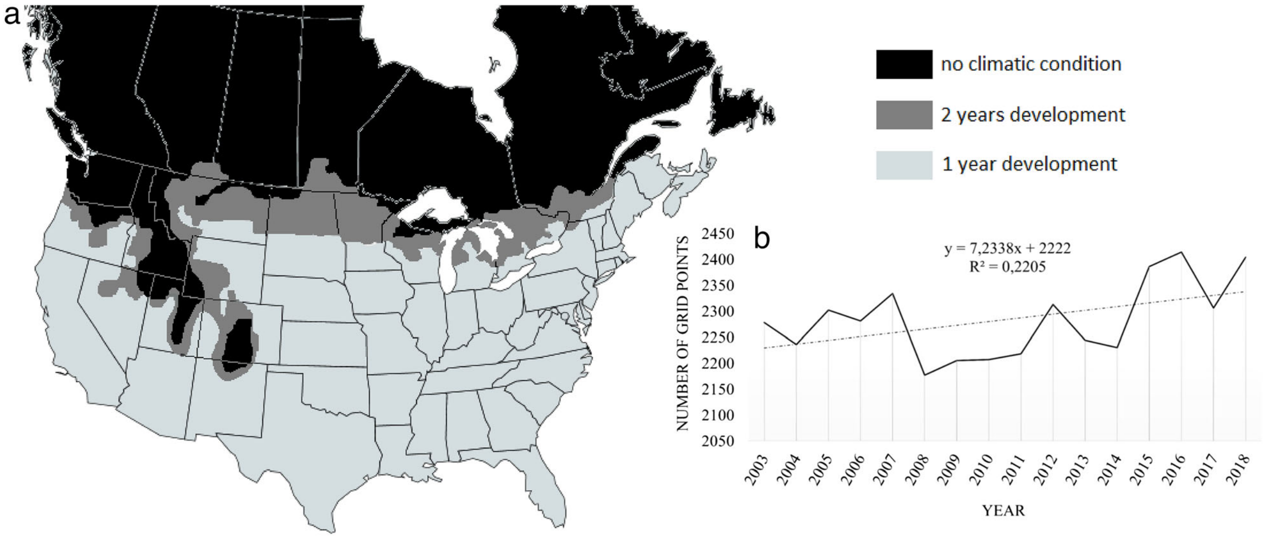

Figure 5 (a) Potential spread of *Trichoferus campestris* according to different ecotypes in North America based on the European Centre for Medium-Range Weather Forecasts' ERA-Interim reanalysis, calculated by mean cumulated temperature, 2003–2018. (b) Number of grid points of the beetle's 1 year life cycle area, 2003–2018.

in affected areas. The most expedient method would be the utilization of pheromone traps, the advancement of which has significantly progressed in the USA (Ray 2017).

Observing the rapid spread of *T. campestris* raises the question of its further expansion in the future (Chen *et al.* 2011). The Holarctic region was examined on a 55.8 km × 55.8 km grid (Dee *et al.* 2011). The theoretical expansion area was based on the climatic element of cumulated temperature reaching N55°. The potential distribution area was divided into two parts, the 1-year and 2-year life cycle regions. The northern border of the 1-year life cycle follows the Avon River in the UK, through southern Denmark, Lithuania, Belarus and Russia. In the Nearctic region the natural border coincides with the administrative boundary between the USA and Canada. The Rocky Mountains is an exception where the climatologically unsuitable area extends into the center of the country. The width of the 2-year life cycle band is approximately 300–400 km in the Palearctic and 200–400 km in the Nearctic regions. This transitional zone is mostly exposed to climate change (IPCC–AR5 2014).

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