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ORIGINAL ARTICLE

Red-headed ash borer *Neoclytus acuminatus acuminatus* (Fabricius) (Coleoptera: Cerambycidae): the global distribution, current spreading and the seasonal activity depending on its different habitats

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Abstract
Holarctic expansion of *Neoclytus acumiantus acuminatus* due to its polyphagous character has been a major concern for plant health, which raises several questions about its spreading directions. I have examined all bibliographical references, phytosanitary reports and authentic photographs from the online sources in the quest of the determination of the worldwide distribution and flight phenology of *N. a. acuminatus*. The expansion, including the western Palearctic regions as well as several Neotropical habitats, is proven and has become more intense in the last decades. It can be found mostly on the Holarctic region including 21 countries, which is supported by 51 publications. Its spreading mostly northward and eastward in the Palearctic is continuous due to anthropogenic effects, climate change as well as movement of infested materials. Flight phenology and population densities as a function of habitats were mapped. The detection in novel habitats of this pest due to imported wood materials and products is envisaged in the foreseeable future. The primary criterion for controlling the species adapted to the commercial trade and climatic change would be the elaboration of a monitoring system in affected and exposed areas.

Keywords Flight phenology · Global distribution · Meta-analysis · *Neoclytus a. acuminatus* · Population density · Range of expansion

Introduction

The red-headed ash borer *Neoclytus acuminatus acuminatus* (Fabricius 1775) (Coleoptera: Cerambycidae) is a wood-boring pest posing major threat to the phytosanitary condition of wood products originating from forests and orchards (Csóka and Kovács 1999; Monné and Nearns 2020) in some regions. However, the beetle is not typically a pest throughout its entire range. So, in North America *N. a acuminatus* is not usually a pest in spite of its broad host range. Its phytosanitary status depends on the prevailing climate, the assortment of available host plants and the presence of its natural enemies (Estay et al. 2009). It is endemic to North America. (Linsley 1964). It was also accidentally introduced into the Adriatic region of southern Europe, where its range of occurrence continues to expand (Bense 1995).

The larvae develop in woody tissues of stressed and dead trees and can degrade hardwood lumber (Waters and Hyche 1984). The most common impact exerted by the pest on humankind is damage caused to felled trees intended for hardwood lumber or firewood. In natural circumstances, red-headed ash borer, as a saproxylophagous species, contributes to healthy forests by hastening the decomposition of dead and dying timber, making more nutrients and space available to healthy plants (Sama 2002; Brelih et al. 2006).

It is extremely polyphagous in deciduous trees (*e.g. Acer, Betula, Castanea, Fagus, Juglans, Populus, Prunus, Quercus, Salix, Ulmus*) and exceptional in conifers (*Abies*) (Brelih et al. 2006). The species will attack nearly all dying and dead hardwoods, but chiefly *Fraxinus, Quercus, Carya, Diospyros*, and *Celtis*. Unseasoned logs of *Fraxinus, Quercus*, and *Carya* with the bark intact are especially subject to heavy attack (Jurc et al. 2016).

It has a wide range of host plants, which makes it possible to find living conditions in diverse habitats. In addition,

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the invasiveness of the species was further strengthened by its vagility and good dispersion ability (Jurc et al. 2016), namely adults capable of flying great distances. The natural spread of *N. a. acuminatus* was unequivocally underscored by these latter facts. The species has excellently adapted to circumstances of freight by ship and plane, because the material of used empties is wood ensuring optimal conditions for the pest. The primary criterion for protection against the species would be the elaboration of a monitoring system in affected areas (Rassati et al. 2016).

The species overwinters as a larva, inside the sawn timber. Consequently, the life cycle of this beetle lasts for one year or (exceptionally) several years to complete. Adult *N. a. acuminatus* are present from March to late July (Bense 1995).

Neoclytus acuminatus acuminatus has well suited excellently to circumstances of freight by ship and plane, as the material of containers ensuring temperate microclimate used is generally wood, hence ensuring optimal conditions for the larvae. In addition, the active spreading via flying is a rather important factor for fast expansion (Rassati et al. 2016).

In spite of all these, special control procedures are not necessary since mainly dying or cut wood is attacked by *N. a. acuminatus*. Controls would be typical for other wood boring insects involving efforts to increase tree vigour through cultural practices, removal of infested wood prior to insect emergence, and treatment of trunks with protective insecticide sprays to coincide with egg laying (Brockerhoff et al. 2006).

The objective of this meta-analytic study was to map the worldwide distribution of *N. a. acuminatus* based on the processing of occurrence data of the species. Besides, among my goals was the determination of the theoretical directions of its spread in different continents as well as visualisation of the adults' seasonal activity and population density based on the online observation records. The acquired data can contribute to learn about the distribution ecology of invasive species through an understanding of the propagation characteristics of this insect.

Materials and methods

Discovery of the current distribution

All bibliographical references, phytosanitary reports and authentic photographic occurrences from the entomological websites in the quest of worldwide distribution of *N. a. acuminatus* have been tried to collect, which were available until August 2020. Several academic search engines [Google Scholar (GS), Web of Science (WoS), Scopus)] and international online insect- and photograph forums (alamy.com, anthrenus.pms-lj.si, BioLib.cz, BugGuide.net, bioras.petnica.rs entomologiitaliani.net, iNaturalist.org, inpn.mnhn.fr, izeltlabuak.hu, macroid.ru, BugGuide.net, whatsthatbug.com) provide primary help to the compilation of this extended database. To the scouting of the new habitats, I used besides the scientific name of the *N. a. acuminatus*, the terms "new/first", "data", "record", "observation" as well as "-interception" as keywords in the mentioned search engines. These observations were recorded and accurately placed on the map using Google Earth®. The spatial distribution of the beetle was visualised by means of GIMP® (2018) (GNU Image Manipulation Program) and MapChart® (2020) software's.

Firstly, the native distribution area was reconfigured based on the studies of Hopping (1932) and Linsley (1964), in which the Nearctic region had formerly been indicated as a potential habitat of this species. Each data set was grouped by chronological order and used for assessing the occurrence of habitats and the present status of *N. a. acuminatus*. In addition, presumed directions of the spreading and actually occupied area of this arthropod were determined by means of further observational records of beetles. Thus, it became possible to prepare the global distribution chart of *N. a. acuminatus* over the whole Nearctic-Neotropical and western Palearctic ranges.

Determination of seasonal activity and population density

The seasonal activity of adult *N. a. acuminatus'* by states and countries by means of the data originating from the former listed online databases containing photographic (alamy.com etc.), observational (BugGuide.net, iNaturalist.org, etc.), and scholarly records (Scopus, WoS etc.) has been determined. The flight season of the year was divided according to the month's quarter marked by serial number (quarter I, II, III and IV). The main flight activity as the states and the countries of adults is shown by green bars. The calculations of the "main" flight activity period were determined by when 80% of all records of adult activity were found to occur. Furthermore, I have visualised the population density regarding the pest pressure based on the online observation records all over the world, which originated from the aforehand-mentioned entomological websites. The data were catalogued, and the population densities were mapped via red shades. For these calculations of population density (d) ($d = r/a \times 10^4$), the number of observation records per unit area (r) and the size of this area in km^2 (a) were taken into consideration.

Results

Expansion and the directions of the global spreading of N. a. acuminatus

Table 1 contains the years of the first observations and present pest-status of *N. a. acuminatus* on the basis of published bibliographical references. Linked to this collection, online incidences are displayed in Table 2 and 3 (due to the large number of data in North America, only a summary table is included here), which completed this related database in whole Holarctic range. The expansion including the main parts of Nearctic and western Palearctic regions is conspicuous, but there are data from several Neotropical habitats as well in the last decades. Apart from Argentinean observations of this species, it can be found mostly on the northern hemisphere. Its presence has been shown in 21 countries (in 44 member states of the USA and 7 provinces of Canada), which is supported by 51 publications and several online reports of occurrences until now. It started to spread from Nearctic areas (where it was an endemic species), northwards, westwards and southwards, while it has reached several woody habitats in the Caribbean and Atlantic Maritime Ecozones. Besides, its western Palearctic spreading foci have encompassed Central Europe, the Balkans and Apennine peninsula from the Adriatic settlement point.

The distribution of the American continent as well as whole Holarctic expansion of *N. a. acuminatus* is shown in Fig. 1. The species is a typically Nearctic faunal element. The beetle is native in mid-east regions of the USA (more precisely New Jersey, Pennsylvania, Illinois, Kansas, Texas and Missouri states). In spite of this, the exact native area of this species cannot be determined, because more related observation records have already been available from different states for more than one century. Probably, the spreading in North-America supported by road traffic has intensified approximately since the beginning of twentieth century.

The beginning and exact time of the continuous south and westward expansion of the new North-American areas are rather obscure, but it is becoming mass and expansion of its Nearctic living place was unequivocally supported by intensifying urbanisation from the beginning of twentieth century. Accordingly, the species has got more observation data from the new habitats, for example from several points of Georgia and Florida states as well as from Idaho (in 1948). *N. a. acuminatus* became one of the most abundant longhorn beetle species in Alabama by 1979. The period of the next notable wave of the Nearctic expansion was in the years following right after the millennium when it has reached coasts of the Pacific Ocean and Atlantic Maritime Ecozones (2002–04). The beetle has presented itself almost all over the USA by now with the exception of Alaska, Montana, Wyoming, Nevada, and Arizona. Missing of the species in these states can be explained by unsuitable climate conditions. These newly occupied Nearctic areas can be assumed to be the primary source of further propagation in some Atlantic regions. Its global spreading started from these habitats, thanks to which *N. a. acuminatus* has been observed in Madeira Islands, the Antilles from the second quarter of twentieth century.

In South-America, *N. a. acuminatus* has been reported to be likely to be established in Argentina after two adults were collected in the field on planted trees before 1954. This south Neotropical presence was confirmed by Di Iorio (2004) much later, who captured two males running on dead branches in the Central-Argentinean village, Bernasconi in 1998.

Accordingly, the first European observations include international harbours or aerodromes, where intense commercial activities were typical after the First World War. The oldest European findings originate from the Croatian city, Fiume (in 1851) (Fig. 2), starting from here with north-, west- and southward active spreading to Dalmatia, Istrian peninsula all the way to Montenegro as well as Po lowland and South Tirol in Italy. These regions can be considered as primary sources of spreading habitats, where its stable populations have been formed.

From this stabile propagation area, the beetle may have arrived through the Dinaric mountains and from the north, bypassing Slovenian and North-Croatian areas to Montenegro, Central-Serbia, and south-eastern Hungary. According to the work of Sama (2002), the most pronounced spreading directions of *N. a. acuminatus* in Europe nowadays are south- and eastward to the Balkan peninsula and Romania, and westward in the Carpathian-basin towards Transdanubia and South-Slovakia.

With regard to the westward direction, *N. a. acuminatus* has quickly occupied north Italy—where its southern border is Tuscany and Umbria in the Apennine peninsula—and reached the southern parts of Switzerland situated at the foot of Alps, Ticino and later Valais cantons. There are some records from the South of France, provinces of Languedoc-Rousillion, Alpes Azur and Rhone-Alps from the 1980s, but recent observations have not confirmed successful settlement in these areas since then.

In parallel to this, this species has emerged in other European locations at the beginning of the 20th century. One individual was reported by Buckle in 1902 in Belfast, which was undoubtedly imported in timber to islands of Ireland. Another, geographically separated focus is the Mark Brandenburg province in Germany, where a remarkable accumulation of *N. a. acuminatus* individuals has

Table 1 The first observation data in order of appearance as well as the presence status on the World of *Neoclytus acuminatus acuminatus* based on bibliographical data

	Country/State	Places of occurrence	Year	Presence status	References
American continent and Atlantic regions					
1	Portugal (P)	Madeira Is.: Selvagens	1937	ep	Picard (1937), Borges et al. (2008), Monné and Nearns (2020)
2	Florida (USA)	–	< 1940		Hoffman (1940)
3	Idaho (USA)	Boise, Nampa, Parma, Payette	1948		Barr and Manis (1954)
4	North Carolina (USA)	Cherokee county	1965		Mount (1965)
5	North Dakota (USA)	Minot	1978		Kelly (1979)
6	Cuba (C)	–	< 1983	oo	Peck (2005), Nearns (2006), GBIF (2019)
7	Argentina (RA)	La Pampa (Bernasconi)	< 1954; 1998		Barr and Manis (1954), Di Iorio (2004)
8	Oregon (USA)	–	2002	ne	Nugent 2005
9	California (USA)	–	2003		Seybold et al. (2016)
10	Washington (USA)	–	2003		USA Congress (2009)
11	Canada (CDN)	New Brunswick, Nova Scotia, Prince Edvard Is	2004	oo	Webster et al. (2009)
12	Puerto Rico (USPR)	Manati	2007		Micheli (2007)
13	Canada (CDN)	Southern Manitoba, Alberta, Saskatchewan	?		Monné and Hovoré (2005), Monné and Nearns (2020)
14	Canada (CDN)	British Columbia	?		iNaturalist 2020
15	Mexico (MEX)	Northern Coahuila, Nuevo Leon, Tamaulipas	?		Aguilar-Perez et al. (2007), Monné and Nearns (2020)
Europe					
16	Croatia (HR)	Rijeka	1851	ep	Küster (1851)
17		Zadar	1891		Jurc et al. (2016)
18	North Ireland	Ulster (Belfast)	1902	oo	Buckle (1902)
19	Italy (I)	Friuli-Venezia Giulia, Veneto	1908	ep	Manzoni (1930), Winckler (1932), Demelt (1950), (1956), Tassi (1969), Sama (2002)
20	Germany (D)	Mark Brandenburg	1914		Reineck (1919), Winckler (1932), Hellrigl (1974)
21		Thuringia	1929		Horion (1974)
22		Hesse, Rhineland-Palatinate	1929–1951		Klausnitzer et al. (2016)
23	Switzerland (CH)	Ticino	1937		Wittenberg (2005), Brelih et al. (2006), Monnerat et al. (2015)
24	Slovenia (SLO)	Gorizia, Coastal-Karst	1949		Brelih et al. (2006)
25	Czech Republic (CZ)	Karlovy Vary, Labem	1951	oo	Heyrovský (1951), Sláma (1998)
26	Italy (I)	Trentino-Alto Adige	1954	ep	Horion (1975)
27	Bosnia-Hercegovina (BIH)	Krajina, Tropolje, Hercegovina	1973		Mikšić and Georgijević (1973), Mihajlović and Stanivuković (2009)
28	France (F)	Provence Alpes Azur, Rhone-Alps	1976	oo	Sudre et al. (1999), Brustel et al. (2002), Cocquempot and Lindelöw (2010)
29		Languedoc-Rousillion (Tharn county)	1980		Villiers (1979), Bijaoui (1980)
30	Hungary (H)	Southern Great Plain, Central Hungary	1984	ep	Csóka and Kovács (1999)
31	Switzerland (CH)	Valais	1992		Wittenberg (2005), Brelih et al. (2006), Cocquempot and Lindelöw (2010), Monnerat et al. (2015)
32	Hungary (H)	Transdanubia	2002	ne	Szeoke and Hegyi (2002)

Table 1 (continued)

	Country/State	Places of occurrence	Year	Presence status	References
33	United Kingdom (UK)	-	< 2002	oo	Sama (2002), Monné and Nearns (2020)
34	Montenegro (MNE)	-	2002	ep	Roganović (2007), Bulatović et al. (2016)
35	Serbia (SRB)	Sumadija and Western Serbia (Mt. Fruška Gora, Mt. Rtanj)	2005		Pil and Stojanovic (2005), Ilić and Ćurčić (2013)
36	Romania (RO)	Western Romania: Timis county (Timisoara)	2005	ne	Manci et al. (2005)
37	Slovakia (SK)	Sturovo	2008	oo	Danilevsky (2014)
38	Slovenia (SLO)	Central Slovenia (Savinja: Brdo pri Kranju)	2012	ne	Jurc et al. (2012)
39	Serbia (SRB)	Central Serbia (Kragujevac)	2014		Vukajlović and Živanović (2015)
40	Austria (A)	Lower Austria (Theiss)	2018	oo, ne	Pennerstorfer and Kriechbaum (2018)

oo occasional occurrence, *ep* established populations, *ne* newly emerged establishing populations

been registered since the beginning of the First World War. The beetle could spread westward to Thuringia, Hesse and Rhine-Palatine. According to Klausnitzer et al. (2016), occasional records were reported from these German provinces. The subsequent westward spread of the species has not reached France or the Benelux states, which is confirmed by the monograph survey of the Luxembourgian insect fauna of Vitali (2018).

Furthermore, a southward advance has been registered in the northern parts of the Czech Republic, where observational data originate from 1951. It should be mentioned, however, that other occurrence from this country has not been reported ever since up to now. The newest European observation data of species originate from north Austria from 2018, where some specimens were found in a fig tree. *N. a. acuminatus* is thought to have been introduced spontaneously through spreading from Germany or mediated by import trade activity from the American continent. Besides, it could inadvertently and occasionally have been imported, although apparently not established in the UK and France. Nevertheless, these records reveal the introduction of these beetles from North America to the European continent which still continues today.

Seasonal activity and population density of *N. a. acuminatus* in the World

It can be seen well the seasonal activity of the species depends on its distribution area characterising different climatic conditions (Fig. 3). However, the main period of adult appearance is between May and June independently of the observational location.

The southern regions both in Nearctic and in Palearctic areas can be characterised by longer adult flight seasons (period of adult activity), *e.g.* South West (from the middle of March until the end of August) and South East regions (from the end of March until the beginning of September) of the USA and the Mediterranean region of Europe (from the beginning of May until the end of July). In these areas, the appearances of *N. a. acuminatus'* adults are prolonged almost in the whole year, which is perfectly exemplified by both the Texan and the Oklahoman records, because in these warmer regions it may be present in the environment longer due to having multiple generations per year.

In contrast, the adult flight activities take place in narrower intervals—firstly at the end of spring and at the beginning of summer—in northern regions. This phenomenon was confirmed such as by Idahoan and Canadian records, where the flight is a rather shorter period, mainly from the middle of June to the end of July. Importantly, the higher population density areas of *N. a. acuminatus* in Nearctic coincide with its native distribution areas ($d = 3.97–8.92$) (Fig. 4). This phenomenon was especially proven by a high number of observational records in the east parts of the USA, *e.g.* Massachusetts ($d = 20.31$) or New Jersey ($d = 18.34$). A similar population density to these original distribution areas was observed in the main European propagation areas ($d = 13,36$) as well.

Discussion

Global expansion mostly in the northern hemisphere and other Atlantic areas of *N. a. acuminatus* was remarkable in the 20th century, which can be primarily explained by intensifying commercial and other transport activities (Pennerstorfer and Kriechbaum 2018). *N. a. acuminatus* has well suited to circumstances of freight by ship and plane, due to the fact that the main material of empties widely used are wood ensuring optimal conditions for the species (Rassati

Table 2 European incidence of *Neoclytus acuminatus acuminatus* in online social networking sites and insect forums

	Place of occurrence	Date	Photo by	URL
Croatia				
1	Istria	Unknown	Vaclav Hanzlik	https://www.biolib.cz/en/image/id39789/
2	Drenje	29.06.2016	Petr Horsák	https://www.biolib.cz/en/taxonimage/id296830/?taxonid=277626
3	Jadransko more	14.08.2019	rubazin	https://www.inaturalist.org/observations/30798754
4	Zagreb	26.06.2020	mpecarevic	https://www.inaturalist.org/observations/50992260
France				
5	St-Armand Montrond	Unknown	tex-anne	https://inpn.mnhn.fr/espece/cd_nom/223101?lg=en
Germany				
6	Unknown	13.03.2015	blickwinkel	https://www.alamy.com/stock-photo-redheaded-ash-borer-red-headed-ash-borer-red-headed-ash-borer-neoclytus-86064176.html
Hungary				
7	Városerdő	24.05.2012	Nagy Zoltán	https://www.izeltlabuak.hu/talalat/2653
8	Szakály	25.05.2014	Balogh Diána	https://www.izeltlabuak.hu/talalat/21852
9	Martfű	31.05.2015	Botka Tibor	https://www.izeltlabuak.hu/talalat/7012
10	Budapest	07.05.2015	NagyS	https://www.izeltlabuak.hu/talalat/47817
11	Hortobágy	30.06.2015	g_katona	https://www.inaturalist.org/observations/22748977
12	Budapest	17.06.2016	lmark	https://www.izeltlabuak.hu/talalat/4682
13	Bogyoszló	19.06.2016	adercsaba	https://www.izeltlabuak.hu/talalat/5631
14	Kalocsa	22.05.2017	kanocpapa	https://www.izeltlabuak.hu/talalat/19260
15	Nádudvar	27.05.2017	Sanyus	https://www.izeltlabuak.hu/talalat/7975
16	Tiszalök	30.05.2017	futor	https://www.izeltlabuak.hu/talalat/8639
17	Szekszárd	11.05.2018	novotnygreta	https://www.izeltlabuak.hu/talalat/42845
18	Öcsöd	21.05.2018	u_1526153055	https://www.izeltlabuak.hu/talalat/27483
19	Törökszentmiklós	11.04.2019	KocsácsJudit	https://www.izeltlabuak.hu/talalat/63660
20	Dunatetétlen	19.04.2019	Marussi Istvánné	https://www.izeltlabuak.hu/talalat/86938
21	Szakály	20.04.2019	Balogh Diána	https://www.izeltlabuak.hu/talalat/61264
22	Baja	21.04.2019	lofos	https://www.inaturalist.org/observations/22824636
23	Törökszentmiklós	21.04.2019	Gabi80	https://www.izeltlabuak.hu/talalat/70773
24	Kiskunhalas	22.04.2019	drymar	https://www.izeltlabuak.hu/talalat/61887
25	Iváncsa	26.04.2019	Benja_HUN	https://www.izeltlabuak.hu/talalat/62619
26	Téglás	12.05.2019	Cilu005	https://www.izeltlabuak.hu/talalat/66316
27	Domaszék	18.05.2019	barnajanos	https://www.izeltlabuak.hu/talalat/93052
28	Ócsa	18.05.2019	gammarusfarum	https://www.izeltlabuak.hu/talalat/72835
29	Abádszalók	26.05.2019	Sylvia Deserti	https://www.izeltlabuak.hu/talalat/70991
30	Székesfehérvár	03.06.2019	Hirvenkurpa	https://www.izeltlabuak.hu/talalat/71085
31	Kakasd	07.06.2019	diocles66	https://www.izeltlabuak.hu/talalat/72560
32	Kistarcsa	11.06.2019	beta1	https://www.inaturalist.org/observations/26803270
33	Mogyoród	12.06.2019	TenPe	https://www.izeltlabuak.hu/talalat/73221
34	Harkakötöny	16.06.2019	drymar	https://www.izeltlabuak.hu/talalat/74197
35	Törökbálint	16.06.2019	Masska	https://www.izeltlabuak.hu/talalat/74200
36	Balatonalmádi	22.06.2019	vargasz	https://www.izeltlabuak.hu/talalat/75926
37	Mogyorós	22.06.2019	sirath	https://www.inaturalist.org/observations/27438349
38	Maglód	02.07.2019	rekuci0120	https://www.izeltlabuak.hu/talalat/78925
39	Budapest	18.04.2020	exjunior	https://www.izeltlabuak.hu/talalat/108815
40	Gárdony	01.05.2020	raerek	https://www.izeltlabuak.hu/talalat/109545
41	Csákvár	02.05.2020	Sipi92	https://www.izeltlabuak.hu/talalat/110200
42	Várdomb	03.05.2020	Hirvenkurpa	https://www.izeltlabuak.hu/talalat/120720
43	Budapest	07.05.2020	czimbalmostamás	https://www.izeltlabuak.hu/talalat/121448
44	Dunakeszi	10.05.2020	rothbarna	https://www.izeltlabuak.hu/talalat/112183
45	Tiszalúc	10.05.2020	babirusza	https://www.izeltlabuak.hu/talalat/112104

Table 2 (continued)

	Place of occurrence	Date	Photo by	URL
46	Ócsa	14.05.2020	Rahmé Nikola	https://www.izeltlabuak.hu/talalat/113454
47	Tiszasziget	17.05.2020	mataschek	https://www.izeltlabuak.hu/talalat/114317
48	Debrecen	19.05.2020	evikicsi2	https://www.izeltlabuak.hu/talalat/114672
49	Budapest	03.06.2020	Rapala Miklós	https://www.izeltlabuak.hu/talalat/120529
50	Magyaregregy	05.06.2020	Bazsi18	https://www.izeltlabuak.hu/talalat/155419
51	Budapest	25.06.2020	Xespok	https://www.izeltlabuak.hu/talalat/128745
52	Zalaszántó	27.06.2020	sampspade	https://www.izeltlabuak.hu/talalat/146754
53	Felsőtárkány	28.06.2020	ferati	https://www.izeltlabuak.hu/talalat/130372
54	Dombóvár	02.07.2020	Huerequ	https://www.izeltlabuak.hu/talalat/130902
Italy				
55	Pavia	05.05.2007	Fumea Crassioralle	http://www.entomologiitaliani.net/public/forum/phpBB3/viewtopic.php?f=145&t=41655&hilit=neoclytus
56	Varenna	20.06.2007	roberto-brembilla	https://www.inaturalist.org/observations/10577800
57	Duino-Aurisina	11.05.2008	Bemisia	http://www.entomologiitaliani.net/public/forum/phpBB3/viewtopic.php?f=145&t=24928&hilit=neoclytus
58	Feltre	12.06.2010	Maw86	http://www.entomologiitaliani.net/public/forum/phpBB3/viewtopic.php?f=145&t=8678&hilit=neoclytus
59	Barolo	25.05.2012	Davide	http://www.entomologiitaliani.net/public/forum/phpBB3/viewtopic.php?f=145&t=38722&hilit=neoclytus
60	Villa Estense	13.06.2013	Marketto	http://www.entomologiitaliani.net/public/forum/phpBB3/viewtopic.php?f=145&t=45400&hilit=neoclytus
61	Strada Provinciale	14.04.2017	marcobertolini	https://www.inaturalist.org/observations/5685566
62	Casanova del Morbasco	28.05.2017	damighez	https://www.inaturalist.org/observations/6407414
63	Torino	07.05.2019	vuillermoz	https://www.inaturalist.org/observations/24878283
64	Milano	06.06.2019	lorenzo_bracchi	https://www.inaturalist.org/observations/26500250
65	Serravalle	15.06.2019	eleonora89	https://www.inaturalist.org/observations/27016045
66	Province of Trento	30.06.2019	apeterlongo	https://www.inaturalist.org/observations/28075337
67	Ferrara	01.08.2019	valentinabuono	https://www.inaturalist.org/observations/29973257
68	Ferrara	02.08.2019	valentinabuono	https://www.inaturalist.org/observations/30164429
69	Boara Polesine	03.09.2019	magister73	https://www.inaturalist.org/observations/32053727
70	Rimini	09.12.2019	farcippo	https://www.inaturalist.org/observations/36496267
71	Provinica de Ferrara	19.05.2020	andreagrossi	https://www.inaturalist.org/observations/46652375
72	Bergamo	20.05.2020	liampasto	https://www.inaturalist.org/observations/46637358
73	Como	22.05.2020	paolamcasale	https://www.inaturalist.org/observations/46827901
74	Strada di Vigheffio	04.06.2020	ciccoman	https://www.inaturalist.org/observations/48564981
75	Mornese	10.06.2020	germanoferrando	https://www.inaturalist.org/observations/52650826
76	Brescia	19.06.2020	jdtodi	https://www.inaturalist.org/observations/50140440
77	Monteroni d'Arbia	26.06.2020	andrea_chemello	https://www.inaturalist.org/observations/50985514
78	Ferrara	26.06.2020	valentinabuono	https://www.inaturalist.org/observations/54419571
79	Ferrara	08.08.2020	velentinabuono	https://www.inaturalist.org/observations/55842949
Montenegro				
80	Kotor	22.05.2020	viktor1608	https://www.inaturalist.org/observations/48265775
Romania				
81	Timiș	06.05.2019	mishuherppunk	https://www.inaturalist.org/observations/24668955
82	Sfanta Elena	20.06.2020	standa	https://www.biolib.cz/en/taxonimage/id185390/?taxonid=277626
SERBIA				
83	Unknown	2009	Dragiša Savić	http://bioras.petnica.rs/slika.php?id=518
84	Unknown	2014	Miloš Popović	http://bioras.petnica.rs/slika.php?id=10162
85	Unknown	2014	Ivan Pančić	http://bioras.petnica.rs/slika.php?id=9966
86	Novi Sad	28.07.2014	Geza Farkas	http://www.photogeza.com/invertebrates/beetles/cerambycidae/slides/33_redheaded_ash_borer.html

Table 2 (continued)

	Place of occurrence	Date	Photo by	URL
87	Koviljski rit	28.07.2014	Geza Farkas	http://www.photogeza.com/invertebrates/beetles/cerambycidae/slides/34_redheaded_ash_borer.html
88	Unknown	2016	Zoran Gavrilović	http://bioras.petnica.rs/slika.php?id=15457
Slovenia				
89	Brje pri Komnu	03.05.2002	Matija Gogala	http://anthrenus.pms-lj.si/animalia/galerija.php?id=PMSL-PZFN_Media-00364
90	Gračišče	23.05.2013	Miroslav Kastelic	http://anthrenus.pms-lj.si/animalia/galerija.php?id=PMSL-PZFN_Media-00364
91	Tinjan	02.06.2018	Mirsolav Kastelic	http://anthrenus.pms-lj.si/animalia/galerija.php?id=PMSL-PZFN_Media-00364
92	Nova Gorica	23.06.2020	Janez Kamin	http://anthrenus.pms-lj.si/animalia/galerija.php?id=PMSL-PZFN_Media-00364

Table 3 Summarising North-American incidence of *Neoclytus acuminatus acuminatus* in online social networking sites and insect forums

States of USA	iNaturalist.org	BugGuide.net	whatsthatbug.com	SUM (Σ)	States of USA	iNaturalist.org	BugGuide.net	whatsthatbug.com	SUM (Σ)
Alabama	10	–	–	10	New Jersey	16	3	2	21
Arkansas	5	–	1	6	New Mexico	17	1	1	19
California	8	–	3	11	New York	25	2	–	27
Colorado	9	–	–	9	North Carolina	23	–	–	23
Connecticut	7	1	–	8	North Dakota	3	–	–	3
Delaware	3	–	–	3	Ohio	40	–	1	41
Florida	5	–	1	6	Oklahoma	16	1	–	17
Georgia	8	2	–	10	Oregon	2	–	–	2
Idaho	3	–	–	3	Pennsylvania	40	5	2	47
Illinois	23	1	–	24	Rhode Island	3	1	–	4
Indiana	7	2	–	9	South Carolina	10	3	–	13
Iowa	5	–	–	5	South Dakota	2	–	–	2
Kansas	16	2	1	19	Tennessee	10	1	1	12
Kentucky	5	3	–	8	Texas	152	1	6	159
Louisiana	18	2	–	20	Utah	12	–	2	14
Maine	6	1	–	7	Vermont	5	–	–	5
Maryland	11	4	–	15	Virginia	32	1	–	33
Massachusetts	22	1	–	23	Washington	9	1	1	11
Michigan	13	–	–	13	West Virginia	2	1	–	3
Minnesota	7	–	1	8	Wisconsin	9	7	2	18
Mississippi	7	–	–	7	*Provinces of Canada*				
Missouri	6	–	1	7	Manitoba	3	–	–	3
Nebraska	15	–	–	15	New Brunswick	8	–	–	8
New Hampshire	5	1	–	6	Quebec	33	–	–	33
					Saskatchewan	2	–	–	2

et al. 2016). The rapid spreading was excellent supported by these special features. In addition, the continuous increase in flights as part of intensifying commercial activity is a rather important factor for the fast expansion provided that the prevailing temperature of its given distribution areas matches with that of its new habitats (Seybold et al. 2016). According to the study of Liebhold et al. (2013), the forest pest species are much more concentrated in the north-eastern region of the USA compared with other parts of the country. The similarity in historical spread among different types of

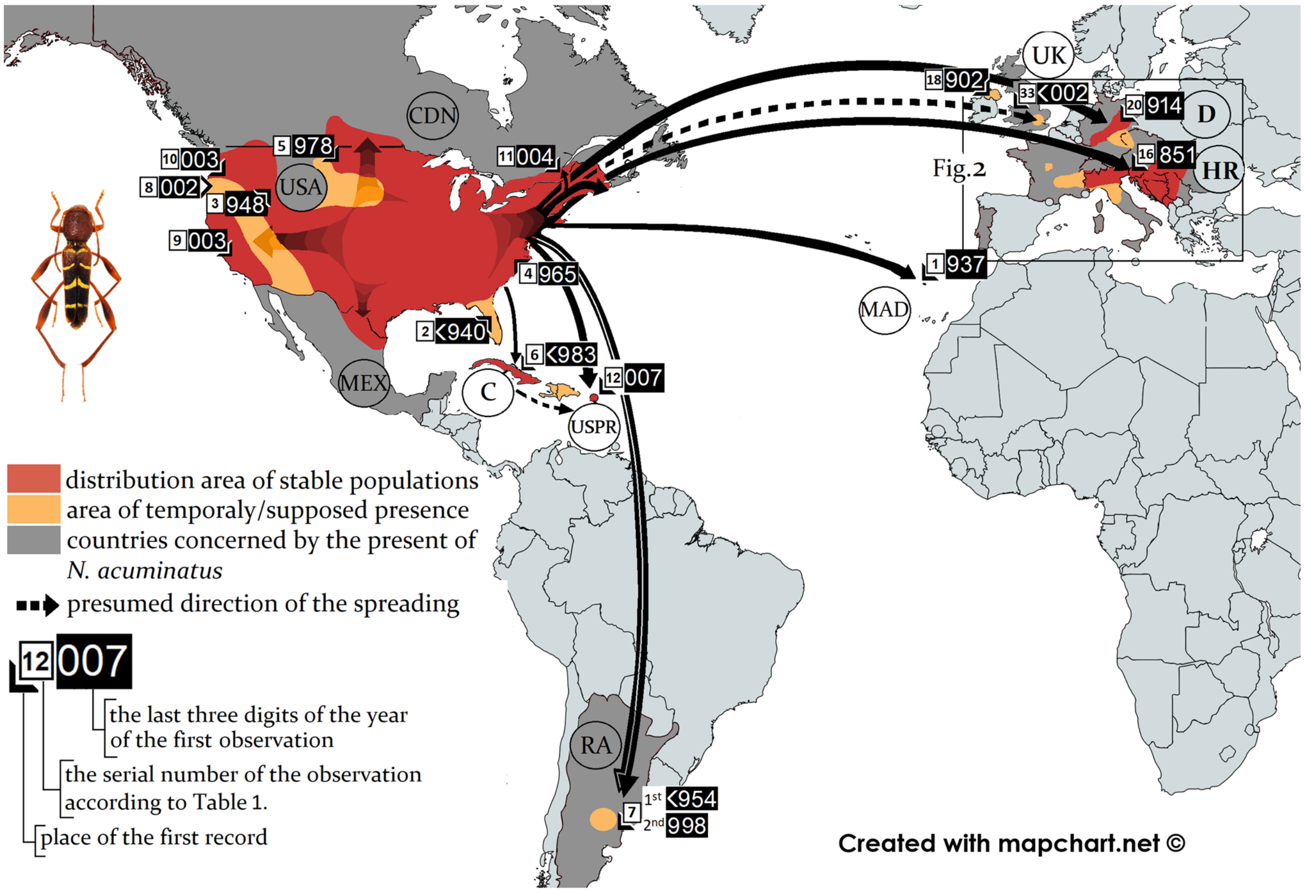

Fig. 1 Main first records, distribution and the theoretical spreading of *Neoclytus acuminatus acuminatus* on the world

organisms indicates the importance of anthropogenic movement in spread.

Hitherto, in the Nearctic areas *N. a. acuminatus* has already gained ground up to the northern boreal forests; only due amount of time is required for the formation of stable populations in these newly occupied areas. The fast process of this propagation will be supported by polyphagous features, ecological flexibility of the pest and the high diversity of woody habitats of these areas (Moné and Hovore 2005; Moné and Nearns 2020).

The Palaearctic and Neotropic introductions mediated by human activity of *N. a. acuminatus* are continuous until now, which is confirmed by more observational data from different parts of the world. Naturally, these introductions have not resulted in stabile populations in all cases, which are exemplified by Argentinean observation as well. It is not known whether some observed specimens originate from temporal introduction or a newly established population (Di Iorio 2004).

The "conquest" of the European continent by the species has been accomplished through air and water trades by import items originating from the USA. With the gradually intensified international transport and trading of commodities from 1850 to 1925, well adaptive species—like *N. a. acuminatus*—have been able to reach Europe alive and become established (Reineck 1919; Sama 2002). To the emergence of the most extensive European propagation source originating from the Mediterranean basin, the optimal background was ensured by the optimal climate and the wide range of potential hosts. These regions have favoured the establishment of more alien species during the last century. For instance, the wood-boring beetles can be easily transported between continents by all kinds of woody materials (Rassati et al. 2016). The further European advance will be probably continued at fast pace in the future.

In general, it can be ascertained that the period of the main activity period of this species is from the beginning of May to the end of June. The prolonged adult activity of the southern regions leads to more generations developing in these areas, which is unequivocally explained by their higher effective temperature regimes (Linsley 1964; Sama 2002). The maximum of the seasonal activity of adult in some European habitats has not reached the native Nearctic observations yet, which is explained by both the differentiation of

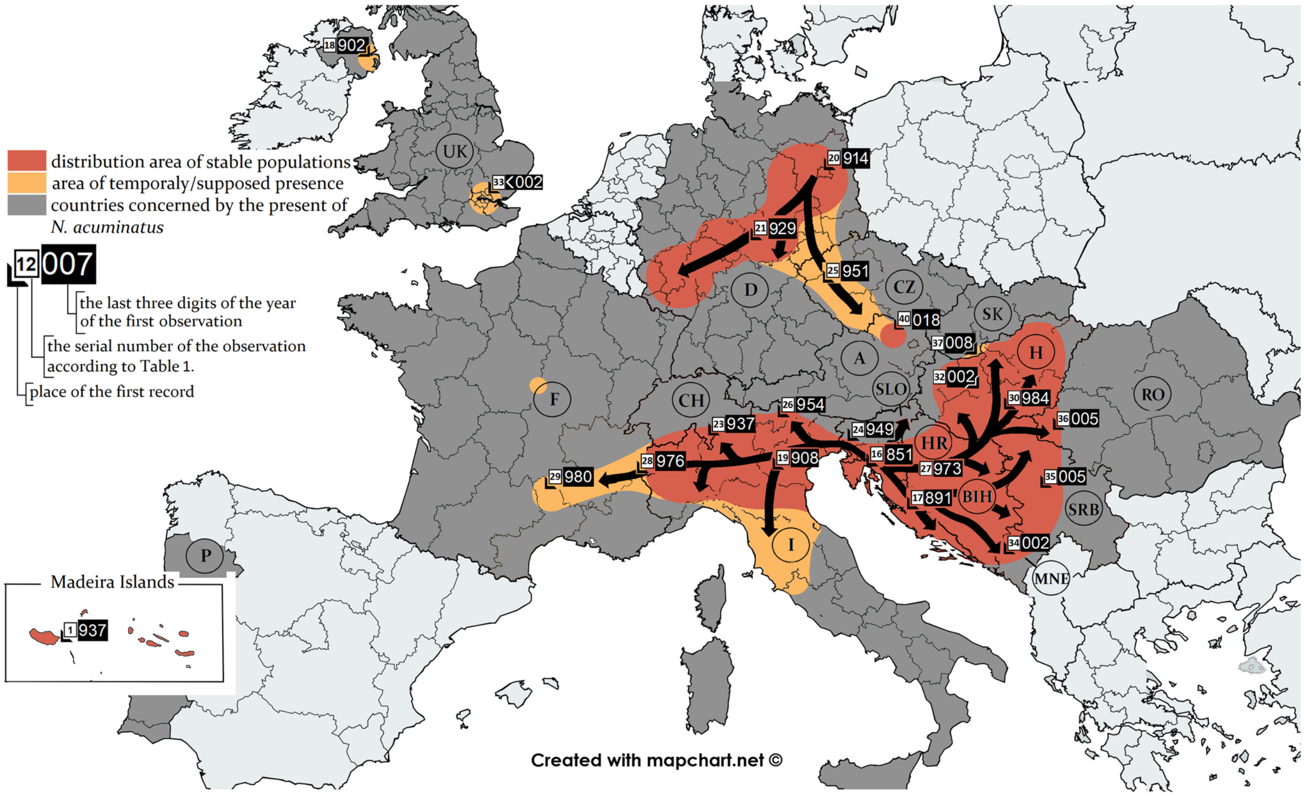

Fig. 2 Occurrence data, distribution and the theoretical spreading of *Neoclytus acuminatus acuminatus* in Europe

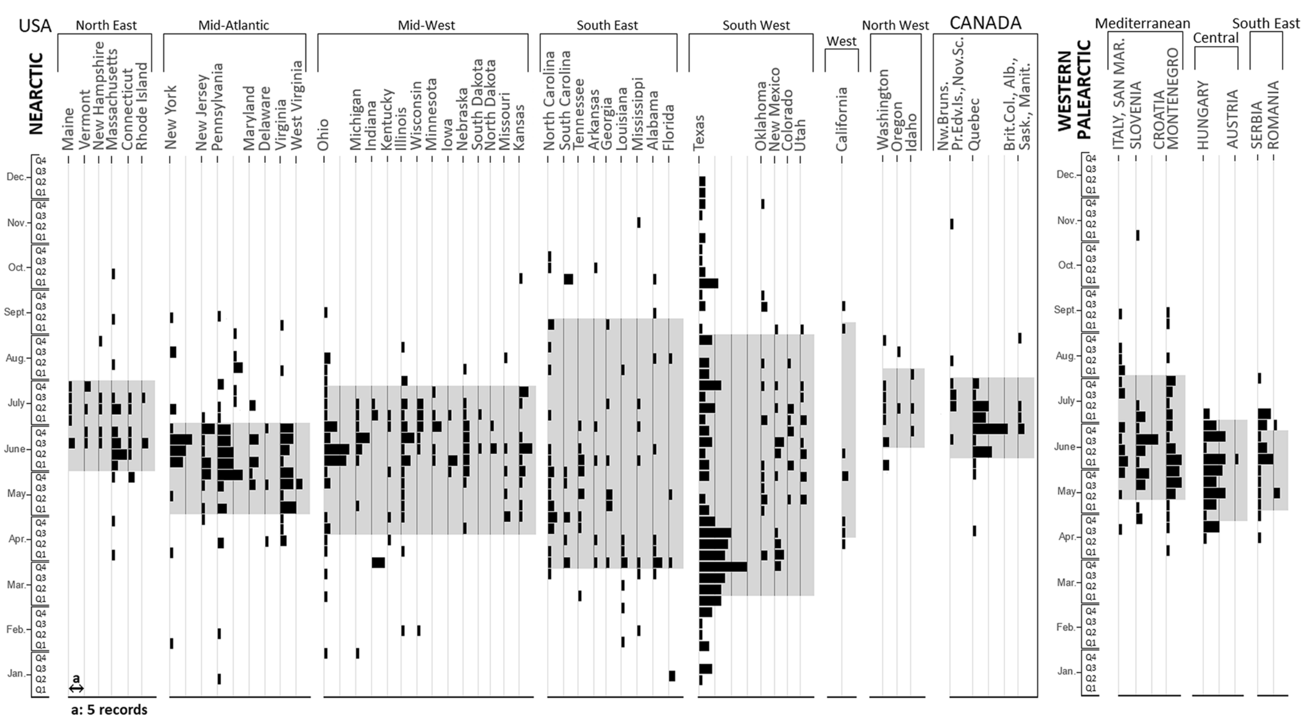

Fig. 3 Seasonal activity of *Neoclytus acuminatus acuminatus* as a function of the states and countries based on the online observation records

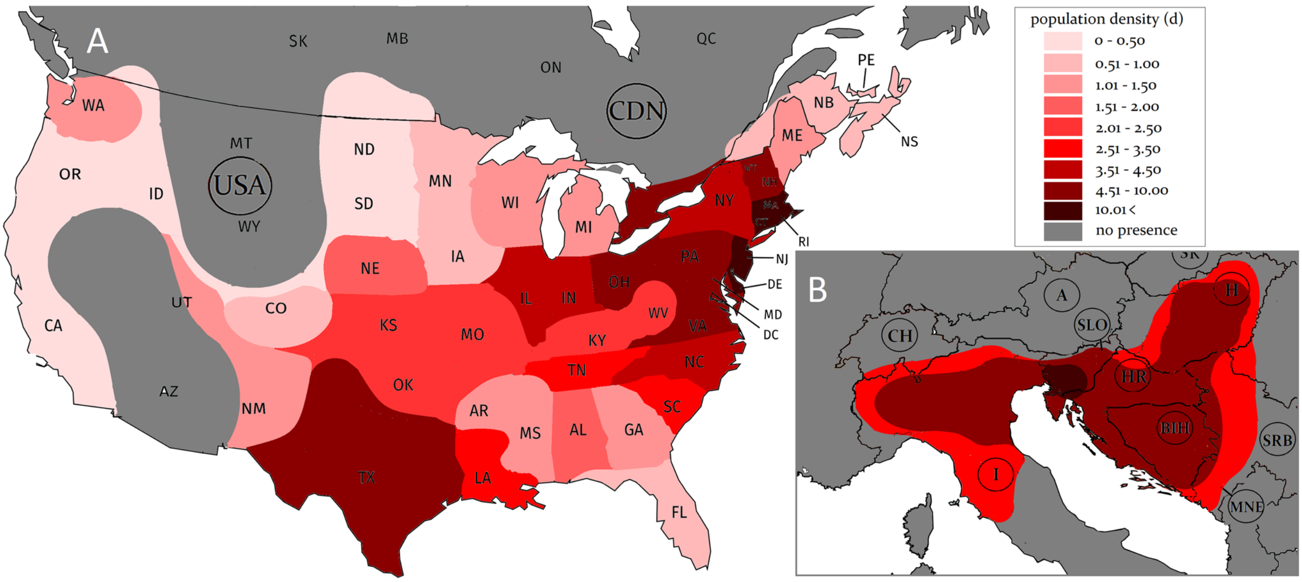

Fig. 4 The estimated population density in the Holarctic range based on the online observation records. **a** North-America; **b**: Europe

temperature amount and not stabilised populations in newly occupied areas.

The mid-west and the eastern regions of the USA are evaluated to be the first propagation areas of *N. a. acuminatus*. The calculated value in the newly occupied area is not represented by higher population density yet, which can be expounded by the ongoing advance of the species. The main European propagation areas can be characterised by a relatively high population density, which is explained by the fast-spreading of the species supported by beneficial climatic and ecological conditions (Westphal et al. 2008; Rassati et al. 2016).

Naturally, my applied method has primarily relied on the documented data sources, which can contribute to the approximate distribution of *N. a. acuminatus*. The main difficulty of such exploration is the searchability and the availability of local bibliographical data. The articles containing the first record of the newly emerged species were only published in a nationally refereed journal in several cases, which could even be written in Cyrillic and are not linked to international databases. The additional trouble with the online records, is that the species observed in the new habitats were poorly identified or uploaded because of the absence of a special entomological knowledge.

The presence of this species due to imported items is presumed in the foreseeable future. The primary criterion for controlling the species adapted to commercial trade and climatic change would be the elaboration of a monitoring system in affected and exposed areas. The aggregation pheromone of *N. a. acuminatus* has been already discovered (Lacey et al. 2004; Fan et al. 2019), which can help to the realisation of a basic global pest monitoring system. The record registered by this international network is able to alarm about the presence of the new habitat and form a situation close to reality.

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Declarations

Conflict of interest The author declare that I have no potential conflict of interest in relation to the study in this paper.

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