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REVIEW

Global distribution and status of introduced Siberian chipmunks *Eutamias sibiricus*

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ABSTRACT

1. Among invasive alien species, squirrels are prominent because of their popularity as pets and their positive perception by the general public. In Europe, populations of five alien squirrel species are reported. The pet trade represents a high-risk pathway for the introduction of rodents, which are likely to become invasive because of their reproductive biology and wide native distribution ranges. In the European Union, a trade ban has been imposed on some particularly impacting species, such as the eastern grey squirrel *Sciurus carolinensis*. Eradication and numerical control is needed for most introduced squirrels in Europe (including the Siberian chipmunk), according to European Union Regulation 1143/2014 on alien species.
2. We summarise the current distribution of the ground-dwelling Siberian chipmunk *Eutamias sibiricus*, one of the most common pet squirrels in Europe and Asia, in its invasive range.
3. Established populations of Siberian chipmunk, in most cases composed of small numbers of individuals, currently occur in France, Switzerland, Italy, Germany, Belgium, the Netherlands, Denmark, and Russia. The species was present in Austria, Sweden, and Hong Kong, and unsuccessful introductions occurred in Spain and the British Isles. The first records from Greece are also reported. Most introductions took place during the 1990s, when individuals were intentionally released (67% of extant populations result from such releases). Population size was correlated with the proximity to urban areas.
4. Human risk of infection with the agent of Lyme borreliosis seems to be the highest where populations of alien Siberian chipmunk occur. Other impacts have never been reported. Competition with native rodents (e.g. the red squirrel *Sciurus vulgaris* and dormice, Gliridae) has been speculated on, as well as predation on nests of native warblers (Sylvidae).
5. Impacts by alien Siberian chipmunks have been overlooked for a long time. Despite this, given that the species may affect native biodiversity and human health, eradication of established populations is recommended.

INTRODUCTION

The Siberian chipmunk *Eutamias sibiricus*, also known as burunduk, is a ground-dwelling squirrel species naturally distributed in north-eastern Eurasia from western Russia to northern Mongolia, Korea, the Kuril Islands, and Japan (Obolenskaya 2008, Thorington et al. 2012, Tsytsulina et al. 2016). Until 2015, all 25 chipmunk species (Thorington et al. 2012) were included within the genus *Tamias*. Then, Patterson and Norris (2016) analysed both morphological and genetic data on Holarctic chipmunks and divided the genus *Tamias* into three genera: (1) *Tamias*, including only the eastern chipmunk *Tamias striatus*; (2) *Eutamias*, including only the Siberian chipmunk; and (3) *Neotamias*, which includes the remaining 23 North American species.

A total of nine subspecies of Siberian chipmunk were identified through morphology and coat-colour analyses (Chapuis 2005, for a review, see Thorington et al. 2012). Obolenskaya et al. (2009) conducted thorough analyses of skull morphology and mitochondrial DNA from specimens of *Eutamias sibiricus* covering all the extent of occurrence of this species. Only three subspecies were identified: *Eutamias sibiricus senescens* distributed in central China, *Eutamias sibiricus barberi* from the Korean peninsula (except for the north-eastern part), and *Eutamias sibiricus sibiricus* from the rest of the range (including the Kuril Islands and Hokkaido, Japan). Recent comprehensive craniometric and genetic studies, based on hundreds of samples, confirmed this subspecific classification (Pisanu et al. 2013, Lissovsky et al. 2017). Genetic distances among subspecies also exceed interspecific distances among other chipmunk species (Lissovsky et al. 2017).

Siberian chipmunks are sold as pets in Europe and Asia (Chapuis 2005, Loiselay 2005, Bertolino 2009, Lee et al. 2011). They currently represent the most commonly traded chipmunk species (Favarelli & Sadino 1983, Gismondi 1990). Thousands of individuals of the Korean subspecies *Eutamias sibiricus barberi* have been introduced through the pet trade in Europe (Chapuis et al. 2011) and, after being released or escaping, have created established alien populations in several countries since the late 1960s (Niethammer & Krapp 1978, Dal Farra et al. 1996, Chapuis 2005, Chapuis et al. 2011). All the available photos of introduced individuals show the morphological features of this subspecies (cf. Obolenskaya et al. 2009).

Alien species are widely reported to be the second greatest cause of the ongoing sixth global biodiversity crisis, after habitat loss (Mack et al. 2000, Wonham 2006). Their impacts may affect local species survival, environmental health, parasitic load of native species, as well as human wellbeing (e.g. Mooney & Cleland 2001, Gurevitch & Padilla 2004, Blackburn et al. 2014, Mazza et al. 2014). Among alien species, squirrels are prominent, being commonly appreciated both as pets and as wild species to be observed (Long 2003, Bertolino & Lurz 2013, La Morgia et al. 2017); this has resulted in nearly 250 squirrel introduction events outside their native range (Bertolino 2009). Four other species of alien squirrel established in Europe have been reported to be detrimental for the conservation of native species and environments: (1) the eastern grey squirrel *Sciurus carolinensis* in the British Isles and Italy (Bertolino et al. 2014, Gurnell et al. 2014); (2) Finlayson's squirrel *Callosciurus finlaysonii* in Italy (Bertolino & Lurz 2013, Mori et al. 2016); (3) Pallas' squirrel *Callosciurus erythraeus* in Belgium, France, the Netherlands, and Italy (Mazzamuto et al. 2017); and (4) the Barbary ground squirrel *Atlantoxerus getulus* in Fuerteventura (Canary Islands, Spain; Lopez-Darias & Nogales 2008).

Management of alien species, particularly of those exerting severe impacts on native ecosystems (i.e. those that are invasive), is based on a detailed knowledge of their geographical ranges (Simberloff 2003, Gallien et al. 2010, Bertolino & Lurz 2013), as also emphasised by European Union Regulation 1143/2014 on invasive alien species. This regulation entered into force on 1 January 2015 and reports a set of management measures to be taken throughout the European Union, as well as a black list of alien species of European concern. Since August 2016, Pallas' squirrel, the eastern grey squirrel, the fox squirrel *Sciurus niger* and even the Siberian chipmunk are included on this list.

Information on single populations of Siberian chipmunks comes from outdated works published decades ago (e.g. Berger 1984, Fossa 1988, Amori & Gippoliti 1995, Dal Farra et al. 1996, Bertolino et al. 2000). Obolenskaya (2008) provided an accurate description of the native range of the Siberian chipmunk, without showing the distribution of this species in the invaded areas, and the maps presented by Jo et al. (2014) and Tsiamis et al. (2017) are incomplete or rough. A synthesis of the current status and distribution of this ground-dwelling squirrel species in its introduced range is therefore required. We reviewed both published and unpublished information available for each country where alien populations of Siberian chipmunk have been reported, and summarise current knowledge on the status and distribution of this introduced squirrel.

METHODS

We conducted a bibliographic search on ISI Web of Science, Scopus, Zoological Records, and Google Scholar, using all combinations of the following terms, in nine languages (English, French, Italian, Russian, Greek, German, Dutch, Spanish, and Portuguese): *Tamias sibiricus*,

Eutamias, burunduk*, Siberian chipmunk*, distribution. The languages we used for our research are the most used in the worldwide scientific literature (Ammon 2001), and we are confident that we covered the entire geographical range of alien populations of the Siberian chipmunk (cf. 'DAISIE' data base: http://www.europe-aliens.org/). Further searches were carried out through (1) an international mailing list concerning alien species (aliens-l@list.auckland.ac.nz); (2) social media networks with public photos (Facebook, Instagram, Twitter); (3) photo and video-sharing websites (Flickr and YouTube); and (4) online data bases (e.g. iNaturalist.org, Global Biodiversity Information Facility – GBIF, Waarnemingen.be, biodiversityireland.ie, Centre Suisse de Cartographie de la Faune), using the same keywords. In all these cases, observers were contacted through emails or private messages (N = 423 messages sent and 265 answers received). Of the 265 replies, 23 were included in our review, as they contained the following information: (1) locations and dates of observation; (2) propagule pressure (i.e. the number of individuals released) if known; and (3) the number of individual Siberian chipmunks observed. Further records for Italy were obtained through a project started at the beginning of 2012, with the aim to collect all coordinates and photos of squirrels ('SaveRedSquirrel'; Mori & Menchetti 2014). We used Pearson correlation tests to assess whether the population size of *Eutamias sibiricus* was correlated with the initial propagule pressure, with latitude, or with proximity to urban areas; single observations (Table 1; Appendix S1) were excluded from these analyses and from the distribution map (Fig. 1).

RESULTS

We retrieved a total of 41 documents (16 articles, 1 PhD thesis, 11 books, 7 technical reports, 5 local biodiversity atlases, and 1 conference proceeding) published between 1974 and 2017 (Appendix S2). Among them, 32% were written in English, 27% in Italian, 17% in French, 15% in German, 7% in Dutch, and 2% in Russian. No documents in Greek, Spanish, and Portuguese were found. Furthermore, 255 occurrences were detected through social networks, photo sharing sites, and sectorial mailing lists.

Excluding locally observed single individuals, a total of 38 populations of Siberian chipmunk were documented outside the native range of the species, resulting from at least 81 introduction events. Of the 38 populations, 30 still exist, 19 of which are in urban parks (Table 1; Fig. 1).

Most of the 81 documented introductions occurred in the 1990s and at the start of 2000s (Fig. 2). Almost 67% of the 30 introduced populations originated from individuals that had been released intentionally, either for ornamental purposes (i.e. those occurring in urban parks or tourist areas: 70%) or by vandalism (i.e. malicious, intentional, and illegal release of individuals, through the destruction of cages or locks: 30%); 17% of the populations originated from accidental escapes from pet shops or breeding farms, and 17% were from unknown sources (e.g. Dal Farra et al. 1996, Wittenberg et al. 2005, Chapuis et al. 2011, Marchant 2012, Bon 2017, Table 1). Local extinctions may have occurred because of consumption by local predators (Dal Farra et al. 1996, Chapuis et al. 2011), starvation (i.e. lack of food supply in urban parks), or cold winter temperatures (Chapuis 2005, Chapuis et al. 2011). Population size was not correlated with initial propagule pressure (r = 0.33, d.f. = 22, P = 0.12) or latitude (r = 0.08, d.f. = 50, P = 0.57); in contrast, it was correlated with the proximity to urban areas (r = 0.75, d.f. = 50, P = 0.03).

Italy

Three populations of Siberian chipmunks are reported to be currently present in Italy, two in Veneto (north-eastern Italy), and one in Rome (central Italy; Bertolino et al. 2015). The oldest is the one in the province of Belluno (north-eastern Italy), where about 100 individuals escaped from a breeding farm in Cesa di Limana and spread throughout the eastern side of the Piave River up to the municipalities of Trichiana, Mel, and Lentiai (Fossa 1988, Bon et al. 1995, Dal Farra et al. 1996, Bon 2017). Some juvenile individuals in dispersal were also observed in Ponte nelle Alpi, Valmorel, and in the Nevegal plateau (Bon 2017, M. Cassol and G. Tormen, personal communication 2017). The last observations date back to 2012, suggesting that the population has crashed or has disappeared. The main woodland where it was present has been felled (EM and RZ, personal observation 2017), and the abundance of feral cats and American mink *Neovison vison* may have helped the extinction process (cf. Dal Farra et al. 1996, M. Villa, personal communication 2017). Another group of individuals (three pairs) was set free in 1978 in Parco Giardino Sigurtà, Valeggio sul Mincio (province of Verona; R. Mattinzioli, personal communication 2017), where they are still abundantly present.

In Rome, fewer than five Siberian chipmunks were deliberately set free by a private owner in the early 1980s in Villa Ada (Monaco 2014). At the start of the 2000s, the population was composed of a very low number of individuals (<10) located in the southern part of Villa Ada (Benassi & Bertolino 2011, Bertolino 2014). This small population might have been maintained for over 30 years by multiple releases (Amori & Gippoliti 1995, Bertolino et al. 2000, Benassi & Bertolino 2011, Bertolino 2014), and because food was provided by park visitors (Monaco 2014). For this area, just one piece of evidence of

Table 1. Status of the Siberian chipmunk in localities in each of the 15 countries included in this review.

Country	Location	First observation	Propagule pressure	Current status	References
Austria	Vienna	1975	>10	Extinct in the 1980s	Niethammer and Krapp (1978) and Essl and Rabitsch (2004)
Belgium	Soignes Forest, Brussels	1960s	>10	Still present (thousands of individuals)	De Keyser (1983), Riegel et al. (2000), and Verbeylen (2003); website Waarnemingen.be (2016)
Belgium	Calmeyn Forest, De Panne	1976	17	Still present (few individuals)	De Keyser (1983) and Verbeylen (2003); website Waarnemingen.be
Belgium	Forest de Beeltjens, Westerlo	1996	>30	Still present (few individuals)	De Keyser (1983) and Verbeylen (2003); website Waarnemingen.be
Denmark	Teglgårdsparken	2008	Unknown	Still present (<10 individuals)	NOBANIS website (2016)
Denmark	Furesø	1990s	Unknown	Extinct in the 1990s	NOBANIS website (2016)
France	Forêt de Senart (Essonne)	1960s	Unknown	Still present (thousands of individuals)	Chapuis (2005), Marmet (2008), Marmet et al. (2009), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Forêt de Meudon (Haut-de-Seine)	1980s	Unknown	Still present (thousands of individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Forêt de la Haute-Pommeraye (Creil, Oise)	1986	Unknown	Still present (thousands of individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Bois de Verneuil-sur-Seune (Yvelines)	1986	Unknown	Still present (thousands of individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Forêt de Versailles-La-Minière (Guyancourt-Yvelines)	1989	Unknown	Still present (hundreds of individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Parc de Sceaux (Haut-de-Seine)	1998	Unknown	Still present (<50 individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Bois de Boissy (Taverny)	1990s	Unknown	Still present (hundreds of individuals)	Chapuis et al. (2011)
France	Parc de la Vallèe au Loup (Chatenay-Malabry, Haut-de-Seine)	1995	Unknown	Still present (<30 individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Parc Henri Seillier (Plessis-Robinson, Haut-de-Seine)	1980s	<100	Still present (<100 individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Forêt d'Ermenonville (Borest, Oise)	1999	Unknown	Still present (<30 individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Commune de Villers-Carbonnel (Somme)	1984	30	Still present (<30 individuals)	Chapuis (2005), Chapuis et al. (2011), and Tsiamis et al. (2017)
France	Forêt de Verrières (Essonne)	2000	1	Not present anymore	Chapuis (2005)
France	Commune de Passy (Haute-Savoie)	1980s	1	Not present anymore	Chapuis (2005)
France	Jardin Public de Monde (Lozère)	1985	Unknown	Extinct in 1987	Chapuis (2005)
France	Jardin des Plantes (Paris)	1969	400	Extinct in 1977	Chapuis (2005)
France	Forêt d'Assenoncourt (Moselle)	1986	3	Extinct in 1987	Chapuis (2005)
France	Forêt d'Ancy (Moselle)	1998	1	Not present anymore	Chapuis (2005)
France	Bois des Dames (Bruay-Labussière, Pas-De-Calais)	1999	1	Not present anymore	Chapuis (2005)
France	Bois de Boulogne (Paris)	1970s	Unknown	Extinct in the 1980s	Chapuis et al. (2011)
France	Nantes	1970s	Unknown	Extinct in the 1980s	Chapuis et al. (2011)
Germany	Freiburg im Breisgau	1976	Unknown	Extinct in 2005	Geinitz (1980) and Münch (2005)
Germany	Münster (Westfalen)	1970s	200	Extinct in the 1980s	Jaeger (1974) and Berger (1984)
Germany	Park Schoental, Aschaffenburg	1990s	Unknown	Still present (<100 individuals)	Schmidt (2004) and Chapuis et al. (2011)

(Continues)

Table 1. (Continued)

Country	Location	First observation	Propagule pressure	Current status	References
Germany	Ingolstadt	1990s	Unknown	Extinct in the 1990s	Schmidt (2004)
Germany	Wuppertal	1990s	Unknown	Extinct in the 1990s	Schmidt (2004)
Germany	Rolandseck, Remagen	2000s	Unknown	Still present (unknown abundance)	Chapuis et al. (2011)
Greece	Foothills of Ymittos mountain, Attika	2009	4	Still present (<10 individuals)	P. Andriopoulos, personal communication
Greece	Antonis Tritsis Park (urban park at a suburb of Athens)	2015–16	2	Still present (<10 individuals)	Unpublished (Facebook group 'Nature of Attica')
Hong Kong	Hong Kong	Before 2000	Unknown	Extinct in the 2000s	Bertolino et al. (2000), Shek (2006), and Smith and Xie (2013)
Italy	'Natura Viva Park', Bussolengo (Verona)	1975	about 30	Extinct in the 2000s	Amori and Gippoliti (1995), Bertolino et al. (2000), Chapuis et al. (2011), and G. Ottolini, personal communication (2017)
Italy	Villa Ada (Rome)	1980s	Unknown	Possibly still present (<20 individuals)	Amori and Gippoliti (1995), Bertolino et al. (2000), Benassi and Bertolino (2011), and Monaco (2014)
Italy	Piave river valley, from Limana to Lentiai (Belluno)	1969–70	70-100	Possibly Still present (<20 individuals)	Bon et al. (1995), Dal Farra et al. (1996), Bertolino et al. (2000), Masseti (2005), and Bon (2017)
Italy	Giardino Sigurtà, Valeggio sul Mincio (Verona)	1978	6	Still present (about 100 individuals)	R. Mattinzioli, personal communication (2017)
Italy	Villa Groppallo, Genova Nervi	1980s	1	Not present anymore	Currado et al. (1987)
Italy	Bosco della Partecipanza Trino Vercellese (Vercelli)	1980s	1	Not present anymore	Currado et al. (1987)
Italy	Bolzano	1980s	1	Not present anymore	Bertolino et al. (2000)
Italy	Padova	1980s	1	Not present anymore	Bertolino et al. (2000)
Italy	Venezia	2000s	1	Not present anymore	F. Ussi, personal communication (2017) and Bon (2017)
Italy	Sarzana (La Spezia)	1993	1	Single individual (for over one year)	F. Ussi personal communication
Italy	Eremo di San Silvestro, Fabriano (Ancona)	1990s	<10	Extinct in the 2000s	Fiacchini (2010) and J. Angelini personal communication (2017)
Italy	Jesi (Ancona)	2009	2	Single observations	Fiacchini (2010)
Italy	Firenze	1970s	Unknown	Several unsuccesful releases	Masseti (2005)
Italy	Prato	1970s	Unknown	Several unsuccesful releases	Masseti (2005)
Italy	Ticino Park (Lombardy)	1995–98	Unknown	Repeated single observations	Masseti (2005) and Nappi and Mancuso (2005)
Italy	Pozzuoli, Oasi WWF Cratere degli Astroni (Napoli)	2001–02	1	Not present anymore	Nappi and Mancuso (2005)
Italy	Bosco di Capodimonte (Napoli)	2002	1	Not present anymore	Nappi and Mancuso (2005)
Italy	Udine	1990s	<5	Not present anymore	Lapini et al. (1996)
Italy	Martignacco (Udine)	1990s	<5	Not present anymore	Lapini et al. (1996)
Italy	Gorizia	1990s	1	Not present anymore	Andreotti et al. (2001)
Italy	Castello di Agliè (Torino)	2012	1	Not present anymore	Unpublished (video on youtube, 2012)
Italy	Montecatini Terme (Pistoia)	2013	1	Not present anymore	'Save Red Squirrel' data base (2013)
Italy	Ravenna (Ravenna)	2013	1	Not present anymore	'Save Red Squirrel' data base (2013)
Italy	Marina di Montemarciano (Ancona)	2010	1	Not present anymore	'Save Red Squirrel' data base (2013)
Italy	Madonna di Campiglio (Trento)	2009	1	Not present anymore	'Save Red Squirrel' data base (2012)

(Continues)

Table 1. (Continued)

Country	Location	First observation	Propagule pressure	Current status	References
Italy	Madonna di Campiglio (Trento)	2015	1	Not present anymore	Unpublished (Facebook group 'Mammiferi italiani – ATIt', 2016)
Italy	Dobbiaco (Trento)	2010	4	Extinct in 2013	T. Fiorenza personal communication (2016)
Italy	Inveruno (Milano)	2017	1	Single individual	Unpublished (Facebook group 'Educare sulle specie alloctone in Italia', 2016)
Italy	Villa Doria Pamphilii	2017	Unknown	Still present, unknown status	A. Monaco personal observation (2017)
Italy	Parco Adamello Brenta (Trento)	2010s	Unknown	Repeated single observations	Unpublished (Facebook group 'Mammiferi Italiani –ATIt', 2016)
Japan	Karuizawa (Honshu)	1980s	Unknown	Still present (<1000 individuals)	Oshida and Yanagawa (2002) and Chapuis et al. (2011)
Russia	Ruzskiy District	2000s	Unknown	Still present (unknown abundance)	Obolenskaya (2008) and Chapuis et al. (2011)
Spain	North-eastern Spain	2000s	>10	Single observations	Tsiamis et al. (2017)
Spain	Sevilla	2000s	1	Single individual	Tsiamis et al. (2017)
Sweden	Unknown locality	Before 2005	Unknown	Unknown	Obolenskaya (2008)
Switzerland	Parc de la Perle du Lac, Geneva	1970s	50	Still present (<100 individuals)	Fernandez (1995) and Wittenberg et al. (2005); website of Centre Suisse de Cartographie de la Faune (2016)
The Netherlands	Tilburg	1972	Unknown	Still present (hundreds of individuals)	Dijkstra and Dekker (2008) and Peeters (2012); Unpublished (Facebook group 'Siberische grondeekhoorns in Tilburg', 2017)
The Netherlands	Weert	2005	Unknown	Still present (<30 individuals)	Dijkstra and Dekker (2008) and Peeters (2012)
British Isles	Berkshire	2005	70	Extinct in the 2000s	Marchant (2012)
British Isles	Sussex	2009	20	Extinct in the 2000s	Marchant (2012)
British Isles	Yorkshire	1999	1	Single	Marchant (2012)
British Isles	Aberdeen	2000s	1	Single individual	Tsiamis et al. (2017)
British Isles	Waterford, Ireland	2000s	1	Not present anymore	O'Rourke et al. (2014)
British Isles	Area of Dùn Garbhàn, Ireland	2000s	2	Not present anymore	O'Rourke et al. (2014)
British Isles	Limerick, Ireland	2000s	1	Not present anymore	O'Rourke et al. (2014)
British Isles	Wicklow, Ireland	2000s	1	Not present anymore	O'Rourke et al. (2014)
British Isles	Dublin, Ireland	2000s	1	Not present anymore	O'Rourke et al. (2014)
British Isles	Fermanagh, Ireland	2000s	1	Not present anymore	O'Rourke et al. (2014)

reproduction is available; a cub recovered at the Wildlife Rescue Centre of Rome in 2009 (L. Ancillotto, personal communication 2016). A few individuals are also present in Villa Doria-Pamphilii (south-eastern Rome), although reproduction in this area has not been verified yet (A. Monaco, personal observation 2017).

A fourth nucleus was present since the late 1980s in Natura Viva Park in Bussolengo (Verona, north-eastern Italy; Amori & Gippoliti 1995, Chapuis et al. 2011); the population consisted of about 100 individuals in the 1990s, but disappeared completely in the 2000s (G. Ottolini, personal communication 2017), maybe because of predation by grey herons *Ardea cinerea* and red foxes *Vulpes vulpes*. Fewer than 10 Siberian chipmunks were also introduced in the surroundings of the Eremo di San Silvestro, in Fabriano (province of Ancona), where they were observed for some years between the end of the 1990s and the start of 2000s (Fiacchini 2010), then disappeared (J. Angelini, personal communication 2017). Four individuals escaped from a pet farm in Dobbiaco (province of Trento) in 2010 (T. Fiorenza, personal communication 2017), but they disappeared in a few days, maybe killed by red foxes.

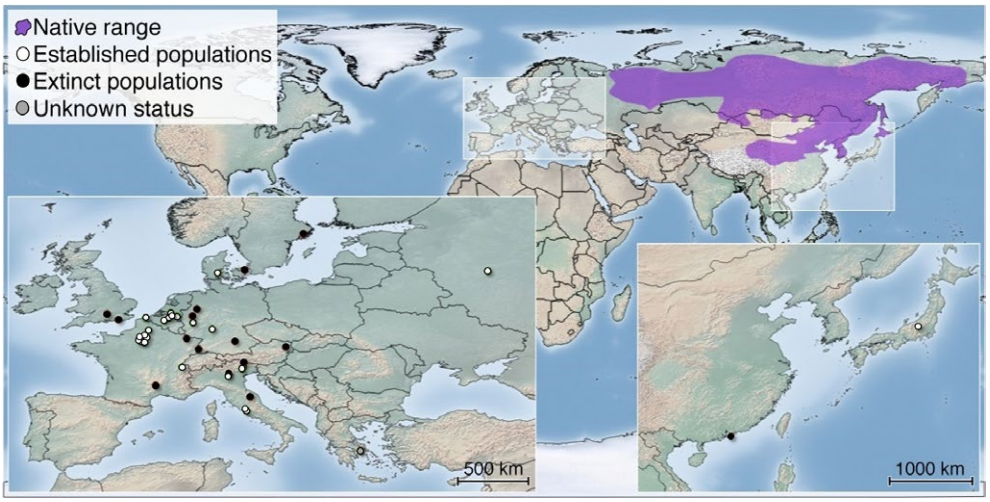

Fig. 1. Native range of the Siberian chipmunk *Eutamias sibiricus*, and distribution of introduced populations in Europe and the Far East (occurrences where $N > 2$ individuals were observed). Extinct populations, established populations, and populations of unknown status are shown. Natural Earth (http://www.naturalearthdata.com) was used to build the map.

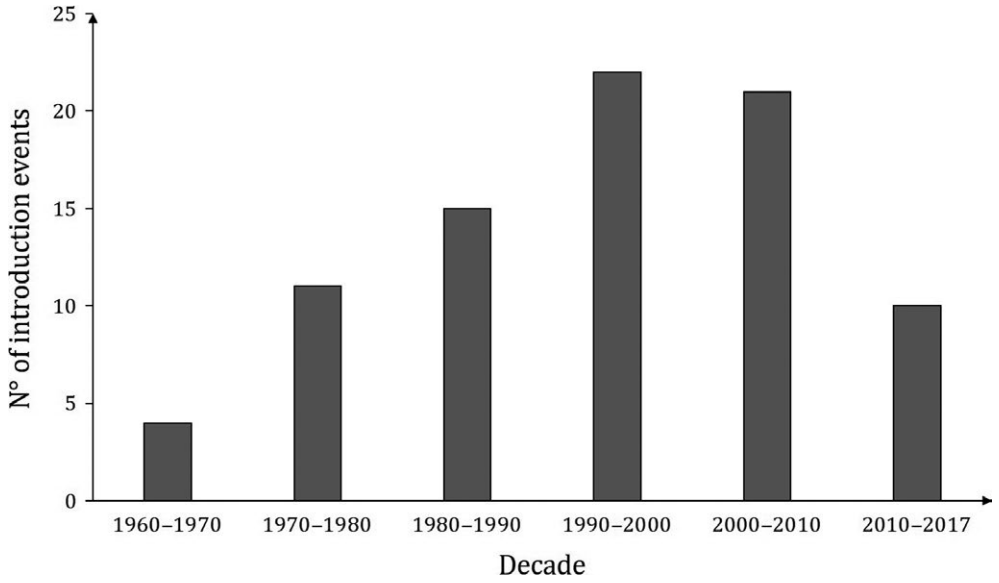

Fig. 2. Numbers of recorded introductions of Siberian chipmunks *Eutamias sibiricus* worldwide in 10-year periods (total $N = 81$).

Single individuals that escaped from pet owners are reported for nine regions (Currado et al. 1987, Lapini et al. 1996, Andreotti et al. 2001, Masseti 2005, Nappi & Mancuso 2005, Bertolino 2008, Table 1).

France

Chapuis (2005) summarised the distribution of the Siberian chipmunk in France, which is the country with the highest number of alien populations of this ground squirrel. The oldest is the population living in Forêt de Sénart, which has been present at least since 1969 (Dozières 2008). This population reached its maximum number of individuals in 2008 (15000; Chapuis et al. 2011), then decreased because of food shortage. Populations of Forêt de Meudon, Forêt de la Haute-Pommeraye, and Bois de Verneuil-sur-Seune, introduced in the 1980s, now consist of thousands of individuals. Hundreds of Siberian chipmunks are currently present in the population of Forêt de Versailles-La-Minière, Guyancourt, introduced in 1989, whereas the population of Parc Henri Sellier, introduced in the 1980s, now has fewer than 100 individuals. In 1984, about 30 individuals escaped from a pet farm in Villers-Carbonnel (Somme), where some chipmunks are still present (Jaouen

& Léger 2005, Chapuis et al. 2011). Four more populations were introduced in the 1990s, the largest in Bois de Boissy (Chapuis et al. 2011). Populations of Parc de Sceaux, Forêt d'Ermenonville, and Parc de la Vallèe au Loup now have fewer than 100 chipmunks each (Chapuis et al. 2011). Populations reported near Nantes, in Jardin des Plantes (Paris), in Forêt d'Assencourt (Moselle), and in Bois de Boulogne near Paris are now extinct (Chapuis 2005, Chapuis et al. 2011).

Belgium

Three free-ranging fluctuating populations of Siberian chipmunk are present in Belgium (De Keyser 1983, Verbeylen 2003, G. Verbeylen, personal communication 2017). Fluctuations are due to variations in food abundance, winter temperature, and rainfall (Chapuis et al. 2011). The largest population is that of Soignes Forest in Brussels, deliberately introduced in the 1960s, which has thousands of individuals (Riegel et al. 2000, Chapuis et al. 2011). Another population of a few individuals, present at De Panne (Calmeyn Forest), originated from 17 individuals that were set free by a pet owner in 1976. Over 30 individuals set free by a pet shop owner were observed in Westerlo (Forest De Beeltjens) in 1996; some individuals are still present in this area (Chapuis et al. 2011).

Germany

Published works report five populations of Siberian chipmunks in Germany (Jaeger 1974, Berger 1984, Schmidt 2004, Münch 2005, Chapuis et al. 2011), but it seems that only two of them are still present: (1) one in Aschaffenburg, with 70–90 individuals set free by pet owners in Schoental Park (Schmidt 2004, Chapuis et al. 2011), and (2) the other in the surroundings of Rolandseck, near Remagen, on the western slopes of the Rhine Valley (Chapuis et al. 2011). Other populations introduced in the late 1960s or early 1970s in the cemeteries of Ingolstadt, Freiburg im Breisgau, and Münster went extinct during the 1990s, probably because of predation by domestic cats and campaigns of rodent control through poisoning (Geinitz 1980, Berger 1984, Schmidt 2004, Chapuis et al. 2011). In Wuppertal (Westphalia), a small population of the eastern chipmunk is still present, but Siberian chipmunks disappeared in early 2000s (Schmidt 2004).

The Netherlands

In the Netherlands, two populations of the Siberian chipmunk are known to occur. The first, in Tilburg, was introduced in 1972 (individuals were deliberately released from a zoological park; Peeters 2012) and now consists of hundreds of individuals. The second is in an urban park in Weert, but it is composed of a small number of individuals (probably <30; Dijkstra & Dekker 2008, Chapuis et al. 2011).

Denmark

The only established population of Siberian chipmunk currently occurring in Denmark seems to be in the urban parks of Teglgårdsparken, north of Silkeborg, although no recent data are available. Fewer than 10 individuals escaped from cages in 2008–09, and a reproductive nucleus still exists (https://www.nobanis.org/species-alerts/tamias-sibiricus/). The population of Furesø (40–50 pairs), introduced at the end of the 1990s, is no longer present, due to eradication efforts and predation by the American mink.

Switzerland

Only one small population of *Eutamias sibiricus* is present in Switzerland. Individuals were introduced during the 1970s by pet owners (Fernandez 1995, Wittenberg et al. 2005), and now form a small, stable population in Parc de la Perle du Lac in Geneva (Chapuis et al. 2011).

Greece

The first records of *Eutamias sibiricus* in Greece were reported on the Facebook group 'Nature of Attica'. A few individuals have been present since 2009 at the foothills of Ymittos mountain (close to the Kaisariani Monastery), as well as, since 2015, at the Antonis Tritsis urban park in Athens (P. Andrioupolos, personal communication 2017). No data are available on their breeding success.

Austria

Between 1950 and 1975, a few individual Siberian chipmunks were recorded in Wien Wilhelminenberg (Schmidt 2004). They were intentionally released by Otto König (a scientist in behavioural studies), but the population went extinct, and chipmunks were not observed in Austria after the 1980s (Bauer & Spitzenberger 1996, Essl & Rabitsch 2004).

Great Britain

Currently, no established population of Siberian chipmunk seems to be present in Great Britain (Harris & Yalden 2008). Many individuals have been observed as single escapes from captivity since 1999 (in Yorkshire and near Aberdeen; Tsiamis et al. 2017); most of them were

recaptured from the wild (Marchant 2012). Two cases of releases due to vandalism are reported: one in Berkshire (70 individuals in 2005) and one in Sussex (20 individuals in 2009; Marchant 2012).

Ireland

No established population of the Siberian chipmunk occurs in the Republic of Ireland or in Northern Ireland currently (Harris & Yalden 2008). During the last 15 years, six individuals have been observed (as single observations) in the Republic of Ireland and one individual in Northern Ireland (O'Rourke et al. 2014).

Spain

Since the start of 2000s, five single observations of Siberian chipmunk have been reported in northern coastal Catalonia, and one single report in Sevilla (Andalusia, southern Spain). No breeding events have been documented in the wild in Spain (Tsiamis et al. 2017).

Other occurrences

Obolenskaya (2008) reported the presence of introduced Siberian chipmunks in Sweden, with no further detail; currently they seem to be absent (M. Joseffson, personal communication 2017). Small breeding populations set free by pet owners are also present in European Russia, in the western part of the Ruzskiy District in the Moskow Region (Obolenskaya 2008). The presence of an alien population of Siberian chipmunks in Hong Kong has been reported by Benassi and Bertolino (2011) and by Thorington et al. (2012), but it is probably extinct, as the species is not listed among alien mammals of this area (Shek 2006, Smith & Xie 2013). Most researchers consider the Siberian chipmunks in Hokkaido (Japan) to be native (Chapuis et al. 2011, Thorington et al. 2012), but they seem to have been introduced in Karuizawa (Honshu) at the end of the 1980s (Oshida & Yanagawa 2002, Chapuis et al. 2011).

ECOLOGY OF INTRODUCED CHIPMUNKS

Very little is known about the ecology of the Siberian chipmunk in its invasive range. This ground-dwelling squirrel is strictly diurnal and it mainly feeds on plant material (Peeters 2012). In Villa Ada Park (Rome, central Italy), Siberian chipmunks were observed feeding on fruits, buds, and flowers on trees (Benassi & Bertolino 2011), despite being regarded as ground-squirrels (Thorington et al. 2012). In their native range, scatter-hoarding behaviour by Siberian chipmunks has been observed, to build up a food reserve for periods of shortage (e.g. early spring and late autumn, immediately before and after winter hibernation: Kawamichi 1989, Thorington et al. 2012). Acorns and conifer seeds are staples of the diet in the native range (Yang et al. 2012, Yi et al. 2012, Jo et al. 2014). At the end of summer and the start of autumn, Siberian chipmunks may supplement their diet with insects (Coleopterans and Hymenopterans) and molluscs (Verbeylen 2003, Peeters 2012).

Hibernation may help alien chipmunks to survive periods of food shortage, lasting from late November to early March at low latitudes (Rome; Benassi & Bertolino 2011, France; Chapuis 2005), and from October to April where winters are colder (Freye 1975, Buskirk et al. 1996, Kawamichi 1996). Winter is spent in underground burrows filled with dry leaves, forbs, and moss (Kawamichi 1989, 1996, Jo et al. 2014). In the native range, the species is typical of coniferous forests and mixed stands (e.g. taiga), as well as of boreal wet glades near rivers (Obolenskaya 2008, Thorington et al. 2012). In their introduced range, Siberian chipmunks are generally observed in areas characterised by the presence of dense underwood and laurel *Laurus nobilis* (Benassi & Bertolino 2011), where they can create burrows and hoard food (Bertolino 2008, Peeters 2012). Home-range size is related to food abundance (Marmet et al. 2009), and trapped individuals in France showed high site fidelity (Marmet et al. 2009, Boyer et al. 2010) and low juvenile dispersal (80–160 m; Marmet et al. 2011).

IMPACTS OF INTRODUCED CHIPMUNKS

Impacts of alien populations of Siberian chipmunk have been overlooked because most populations have restricted ranges (Marmet 2008, Bertolino et al. 2015) and the species has poor dispersal abilities (Marmet et al. 2011); thus, Siberian chipmunks are thought to affect local biodiversity less than other introduced squirrel species. Competition with native red squirrels and dormice (*Glis glis* and *Eliomys quercinus*, Gliridae) has been suggested (Thorington et al. 2012), but no data are available. Chapuis (2005) suggested that Siberian chipmunks might outcompete native bank voles *Myodes glareolus* and wild mice *Apodemus* spp. in France, as the chipmunks can search for food both on tree branches and on the ground. Research conducted in France showed that the Siberian chipmunk is the main reservoir of *Borrelia burgdoferi* sensu lato and that individuals host larger numbers of hard ticks than native bank voles and wood mice (Vourc'h et al. 2007, Dozières 2008, Marsot et al. 2011, 2013). Therefore, the risk of Lyme borreliosis in humans is increased where alien Siberian chipmunks are present (Marsot et al. 2013, Vourc'h et al. 2016), and a role in spillback to native voles has also

been suggested (Marsot et al. 2011). No research has been carried out yet on other diseases or parasites potentially carried by alien chipmunks. A potential positive effect of the chipmunks, if such effects of invasive species can exist, is that introduced chipmunks may represent important prey for alien predators, including feral cats and dogs (Dal Farra et al. 1996, Chapuis et al. 2011, Marchant 2012).

The decline and local extinction of 12 bird species in the Soignes Forest (Belgium) was found not to be due to Siberian chipmunks, though chipmunks may have been involved in the decline of the Eurasian wren *Troglodytes troglodytes* in the same area (Riegel et al. 2000).

DISCUSSION

The Siberian chipmunk, particularly its Korean subspecies, is the only chipmunk that has established populations outside its native range, with the exception of *Tamias striatus* in Westphalia (Long 2003, Chapuis et al. 2011). Most releases were carried out during the 1990s, following the high number of individuals exported per year from Korea up to the 1980s (Mitchell-Jones et al. 1999, Chapuis et al. 2011). The Siberian chipmunk has all the features of a 'good invader', having (1) a wide native distribution range (Obolenskaya 2008, Thorington et al. 2012, Jo et al. 2014); (2) great adaptability; and (3) a high reproduction rate. In contrast to all the American chipmunk species, the Siberian chipmunk may produce two litters each year, and is therefore one of the most prolific squirrel species (Corbet & Hill 1992, Chapuis 2005). Despite this, we document that out of 53 introduction events of Siberian chipmunks involving more than one individual, only 38 populations became established at least for a few years, and only 30 populations (i.e. 57%) are still present outside the native range. Establishment success of Siberian chipmunks was not related to initial propagule pressure or to latitude, whereas it markedly increased with increasing proximity to urban areas. Over 60% of the alien populations of Siberian chipmunk occurs in urban parks. Squirrels in urban areas (e.g. urban parks, rivers) are greatly appreciated by humans, often representing a tourist attraction because of their tameness (Parker & Nilon 2008) and their nice aspect (Bertolino & Lurz 2013). Accordingly, Chapuis (2005) reported a very high level of appreciation of Siberian chipmunks by visitors in French parks. Furthermore, food supply by humans may have increased the survival of introduced squirrels within human settlements (Jessen et al. 2010, Chapuis et al. 2011). Habitats surrounding urban parks may limit range expansion by introduced chipmunks, which may explain the low population densities (Chapuis et al. 2011) and the limited dispersal abilities showed by this species in Europe (Marmet et al. 2011). The high extinction rate of introduced populations seems to be mostly due to predation by synanthropic predators, such as American mink, red foxes, grey herons, and domestic or feral cats and dogs (e.g. Dal Farra et al. 1996, Benassi & Bertolino 2011, Chapuis et al. 2011, Marchant 2012). In contrast, Chapuis (2005) suggested that chipmunks introduced to Europe may have a great potential to increase their population and to spread, both by natural means or helped by humans.

Among introduced squirrels, the eastern grey squirrel and *Callosciurus* species are described as invasive, because of their ability to spread and because of the impacts they exert on native environments (Bertolino & Lurz 2013, Bertolino et al. 2014), even when populations start from low numbers of founders. Until now, little attention has been paid to alien chipmunks, despite their wide distribution outside their native range. The presence of this species on the list of invasive species of European concern (European Union Regulation 1143/2014) is due to the impact it may exert on human health by the transmission of the aetiological agent of Lyme borreliosis (Vourc'h et al. 2016). Accordingly, in Europe, human risk of infection with *Borrelia burgdorferi* sensu lato, the agent of Lyme borreliosis, seems to be the highest where populations of alien chipmunks occur (e.g. north-eastern Italy, northern France, central Belgium; Hubàlek & Halouzka 1997). Other impacts of introduced chipmunks have been only suggested (e.g. the reduction in the breeding success of the Eurasian wren) or speculated on (e.g. competition for food with native squirrels and dormice, predation on native warblers), and require further study. Field investigations are also required to confirm the presence of some populations, which may have become extinct or dramatically reduced (e.g. in Italy, Denmark, Greece), as well as to assess the parasitological status of all the European alien populations. Low population densities and abundance, as observed for most Siberian chipmunks in Europe, is a key factor promoting successful eradication, which is the recommended operation by international law (European Union Regulation 1143/2014) and national laws (e.g. Italian National Law 157/1992) on wildlife management (Genovesi & Shine 2004). Most squirrel species can easily be trapped, and therefore removal actions would not be difficult, particularly when populations are composed of low numbers of individuals, for example at the start of invasions or when fluctuating numbers are low.

Measures other than eradication have been proven to be ineffective to control the spread of alien squirrels (e.g. Lioy et al. 2016). In contrast, eradication of alien squirrels is often opposed by animal right organisations, due to the appeal which squirrels may exert on the general public, especially in urban areas (e.g. Bertolino & Genovesi 2003, La Morgia et al. 2017).

Trade restrictions and trade bans have been decreed for the most invasive squirrel species in some European countries (e.g. the trade ban for *Callosciurus erythraeus*, *Sciurus carolinensis,* and *Sciurus niger* in Italy: National Ministerial Decree 24/12/2012), but the Siberian chipmunk is still widely sold (Chapuis et al. 2011, Tsytsulina et al. 2016). Given the impacts of alien squirrels on native biodiversity and their popularity as pets (Bertolino 2009, Chapuis et al. 2011, Bertolino & Lurz 2013), a thorough public education campaign should be conducted for the management of these invasive rodents (Bremner & Park 2007).

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Appendix S1. Observations of documented single releases and escapes of *Eutamias sibiricus* in Europe (see Table 1). Natural Earth (http://www.naturalearthdata.com) was used to build the map.

Appendix S2. The 41 documents, published between 1974 and 2017, that were used to source information about introduced populations of *Eutamias sibiricus* worldwide.