Risk assessment template developed under the "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention" Contract No 07.0202/2017/763379/ETU/ENV.D.2[1]

Name of organism: *Callosciurus finlaysonii* (Horsfield, 1823)

EN: Finlayson's Squirrel, variable squirrel; IT: Scoiattolo di Finlaysoni; D: Finlayson-Hörnchen; FR: Écureuil de Finlayson; NL: Finlaysoneekhoorn, finlaysonklappereekhoorn, Thailandeekhoorn, Thaise eekhoorn, variabele eekhoorn

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[1] This template is based on the Great Britain non-native species risk assessment scheme (GBNNRA).

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Risk Assessment Area: The risk assessment area is the territory of the European Union (excluding the outermost regions) and the United Kingdom.

Peer review 1: Craig Shuttleworth, Bangor University, United Kingdom
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This risk assessment has been peer-reviewed by three independent experts and was discussed during a joint expert workshop. Details on the review and how comments were addressed are available in the final report of the study. Cover photo Tim Adriaens with permission.

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Positive opinion by the Scientific Forum: 20 November 2019

Contents

RISK SUMMARIES			
	RESPONSE	**CONFIDENCE**[2]	**COMMENT**
Summarise Entry[3]	likely	medium	*C. finlaysonii* is already present in the risk assessment area after escapes and releases in Southern and Northern Italy. The primary pathway was release of captive animals in parks and woodlands. As the zoo and pet pathways are still active and the current populations represent a potential source of entry/translocation/natural dispersal to other parts of the RA area, the probability of entry is high. However, little information is available on the number of squirrels sold, kept as pets or kept in zoos.
Summarise Establishment[4]	very likely	high	The species is already established in Italy. It is adaptable and can thrive well in new areas when food and nesting places are available. In urban areas supplemental feeding is suspected to facilitate its establishment. *Callosciurus* squirrels are known to establish populations from few founders. The species distribution model predicts suitable areas for establishment in the Mediterranean, Continental and Atlantic bioregion. This is corroborated by successful establishment of other tree squirrel species with a comparable native range. Moreover, *C. finlaysonii* is very tolerant to woodland degradation and fragmentation.
Summarise Spread[5]	moderately	medium	Quantitative studies on the sequential spread through suitable habitats and the possibilities of long distance colonization are not available for this species. However, the spread in southern Italy was rapid after an initial lag-phase and the animals tripled their distribution range in four years, and increased their range 8.5 times in ten years. The total colonized area was 26 km^2 in 2005 but is

[2] In a scale of low / medium / high, see Annex III

[3] In a scale of very unlikely / unlikely / moderately likely / likely / very likely, see Annex I

[4] In a scale of very unlikely / unlikely / possible / likely / very likely, see Annex I

[5] In a scale of very slowly / slowly / moderately / rapidly / very rapidly

			currently estimated at 580 km^2. In case of new introductions in other countries, spread could be moderate to large, depending on the habitat and landscape context. Human translocations can promote the spread of the species.
Summarise Impact[6]	moderate	medium	In Italy, the most evident damage caused by *C. finlaysonii* is bark stripping. Damage to ornamental trees or nurseries can be important, though this has not been quantified in economic terms so far. Bark stripping increases the risk of fungal infections and invertebrate damage, which ultimately can reduce timber yield. Damage to electric cables and other infrastructure by the species have also been reported. Data on impacts on native species and ecosystems are missing. However, impact can be inferred from other alien squirrel introductions in many European countries. Notably, interspecific competition with native species is likely as particularly, both *S. carolinensis* and *C. erythraeus* are already threatening European red squirrel populations. The species is considered a predator of birds' nests in its native range, but no information is available for the introduced range. Transmission of pathogens could likely cause a risk but, currently, it is not documented. The potential impact on native such as the red squirrel or the endemic Calabrian black squirrel, woodland birds or dormouse is unknown but likely, especially considering impacts of other alien (tree) squirrels introduced and established in Europe.
Conclusion of the risk assessment[7]	High	medium	*Callosciurus finlaysonii* is already present in Italy and the population in the South is rapidly expanding its range in recent years. The primary pathway for entry involves the escape or deliberate release of animals from captivity and

[6] In a scale of minimal / minor / moderate / major / massive, see Annex II

[7] In a scale of low / moderate / high

			the species is kept, bred, exchanged and traded in Europe; therefore, new escapes or releases are likely. Climatic constraints do not seem to hamper successful establishment. The species profits from anthropogenically influenced landscapes and can establish from a limited number of founders. Damage through bark stripping can be considerable and impact on native species through competitive interactions is likely considering the impact of other exotic (tree) squirrels in Europe and the fact that *C.finlaysonii* now occur syntopic in the same habitat *S. vulgaris*. Confidence in the risk assessment is medium to high for establishment, spread and damage to forestry and plantations. Assessment of impact is medium confidence as data on the possible impacts on native species are absent, for the lack of specific studies, but are inferred from other squirrel species. The impacts of *C. finlaysonii* on native species and ecosystems should be better investigated. Also, the possible role of the species in disease transmission, with introduced individuals acting as vector or host of pathogens that can harm native wildlife (and potentially humans) represents a knowledge gap and should be investigated.

Distribution Summary:

The columns refer to the answers to Questions A6 to A12 under Section A.
The answers in the tables below indicate the following:

Yes recorded, established or invasive
– not recorded, established or invasive
? Unknown; data deficient

EU Member States and the United Kingdom

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Austria	–	–	Y	–
Belgium	–	–	Y	–
Bulgaria	–	–	–	–
Croatia	–	–	Y	–
Cyprus	–	–	?	–
Czech Republic	–	–	–	–
Denmark	–	–	–	–
Estonia	–	–	–	–
Finland	–	–	–	–
France	–	–	Y	–
Germany	–	–	Y	–
Greece	–	–	Y	–
Hungary	–	–	–	–
Ireland	–	–	–	–
Italy	Y	Y	Y	Y
Latvia	–	–	–	–
Lithuania	–	–	–	–
Luxembourg	–	–	Y	–
Malta	–	–	?	–
Netherlands	–	–	Y	–

Poland	–	–	–	–
Portugal	–	–	Y	–
Romania	–	–	–	–
Slovakia	–	–	–	–
Slovenia	–	–	Y	–
Spain	–	–	Y	–
Sweden	–	–	–	–
United Kingdom	–	–	?	–

Biogeographical regions of the risk assessment area

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Alpine	–	–	–	–
Atlantic	–	–	Y	–
Black Sea	–	–	-	–
Boreal	–	–	–	–
Continental	Y	Y	Y	Y
Mediterranean	Y	Y	Y	Y
Pannonian	–	–	–	–
Steppic	–	–	–	–

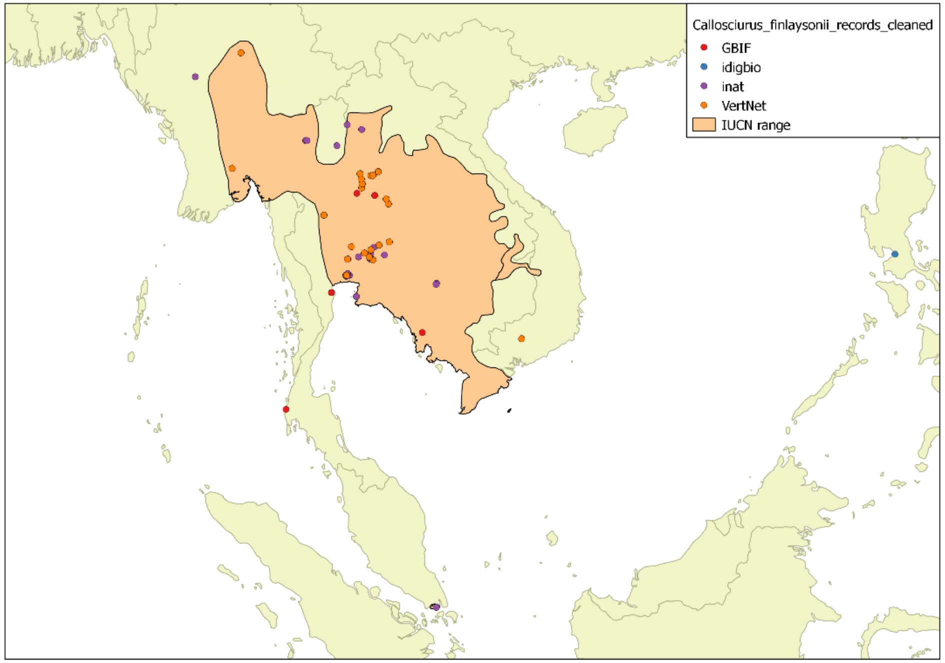
Marine regions and subregions of the risk assessment area

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Baltic Sea	NA	NA	NA	NA
Black Sea	NA	NA	NA	NA
North-east Atlantic Ocean	NA	NA	NA	NA
Bay of Biscay and the Iberian Coast	NA	NA	NA	NA
Celtic Sea	NA	NA	NA	NA
Greater North Sea	NA	NA	NA	NA
Mediterranean Sea	NA	NA	NA	NA

Adriatic Sea	NA	NA	NA	NA
Aegean-Levantine Sea	NA	NA	NA	NA
Ionian Sea and the Central Mediterranean Sea	NA	NA	NA	NA
Western Mediterranean Sea	NA	NA	NA	NA

SECTION A – Organism Information and Screening	
Organism Information	**RESPONSE**
A1. Identify the organism. Is it clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank?	● a list of the most common subspecies, lower taxa, varieties, breeds or hybrids This risk assessments deals with *Callosciurus finlaysonii* (Horsfield 1824) (Chordata, Mammalia, Rodentia, Sciuridae). The species can be adequately distinguished from other entities of the same genus. Common names: EN: Finlayson's Squirrel, variable squirrel; IT: Scoiattolo di Finlaysoni; D**:** Finlayson-Hörnchen; FR: Écureuil de Finlayson; NL: Finlaysoneekhoorn, finlaysonklappereekhoorn, Thailandeekhoorn, Thaise eekhoorn, variabele eekhoorn Sixteen subspecies (nine mainland and seven island subspecies) have been reported (Lurz 2014), some of which have very restricted distributions (Corbet and Hill 1992; Timmins and Duckworth 2008). There are several subspecies and yet to be classified forms in Thailand, Laos and Vietnam, some of which have localised ranges. A revision of the taxon is necessary to evaluate if one or more cryptic species are present (Duckworth et al. 2008). The animals of the invasive populations in Italy have size and fur color similar to that described by Lekagul and McNeely (1988) for a population localized at Thonbury north of Ayutthaya (Thailand), which are smaller than other subpopulations of this species. The Thonbury population was included in the subspecies *C.* f. *bocourti* by Corbet and Hill (1992)
A2. Provide information on the existence of other species that look very similar [that may be detected in the risk assessment area, either in the wild, in confinement or associated with a pathway of introduction]	The native Calabrian black squirrel *Sciurus meridionalis* is completely black with white belly and can easily be recognized from *C. finlaysonii* by people familiar with squirrels (Wauters et al. 2017). It must be noted however that there are *C. finlaysonii* morphs that are completely black or white. The absence of ear-tufts is a useful first guide to distinguish the species from the Eurasian red squirrel *Sciurus vulgaris*, which, however, could lose ear-tufts in summer. In Italy, typical colour morphs have a mostly olive brown back and cinnamon coloured tail, but this colour pattern shows a lot of variation (sometimes dark grey or brown back and/or tail, sometimes the tail underside or the entire tail is completely pale/white). Normally, there is a sharp line between the dark back and (yellow) white or isabel (pale grey-yellow) coloured belly (see also Mazzoglio et al. 2007). This fur coloration is different from the red to brown-black typical of *S.*

	vulgaris, but some confusion may arise in non-expert people. Coat colour in Finlayson's squirrels varies greatly between individuals and between subspecies/colour varieties within subspecies (see e.g. http://www.ecologyasia.com/verts/mammals/variable-squirrel.htm). Animals can range from all white, to all red, to all black. Due to the variability of the coat colour of this species, it is often referred to as variable squirrel (Bertolino et al. 2000; Thorington et al. 2012). Therefore, animals traded may be different from those present in Italy. The most closely related species is Pallas' squirrel *Callosciurus erythraeus* (Pallas, 1779), which also has variable colour morphs (Boonkhaw et al. 2017). Oshida et al. (2007) and Timmins and Duckworth (2008) suggested that *C. finlaysonii* may hybridize with *C. erythrae*us. Timmins and Duckworth (2008) noted 8 suspected hybrids around Phou Xang He NPA (Laos) in the 1990s, both captive and in markets. Additionally, two studies, conducted in Japan and Argentina, described individuals from several invasion foci that were morphologically identified as *C. erythraeus* but genetically closer to *C. finlaysonii* (Oshida et al. 2007; Gabrielli et al., 2014). In fact, *C. erythraeus* and *C. finlaysonii* can be regarded as sister species and Timmis and Duckworth (2008) refer to a *C. erythraeus*-*C. finlaysonii* complex. According to the available literature (e.g. Timmins & Duckworth, 2008; Gabrielli et al., 2014) the taxonomy of both species is complicated and a thorough systematic revision is necessary. Similar species: Prevost squirrel *C. prevosti* can be distinguished from *C. finlaysonii* by its reddish-orange underparts and the whitish thighs and flanks in most subspecies. Grey-bellied squirrel *C. caniceps* has a light grey or silvery belly, and in the dry season turns orange-brown above. Pallas' squirrel *C. erythraeus* is usually more agouti olive brown/grayish olive on the back, with an orange to reddish tint on the belly, and often with some black on the tail (More & Tate 1965; Chapuis *et al*. 2012; Mazzamuto et al. 2016). Plantain squirrel *C. notatus* is easily identified by the two cream and black stripes on the sides in combination with the orange belly. These cream and black stripes also occur in Black-banded squirrel *C. nigrovittatus* but this species has a grey belly.
A3. Does a relevant earlier risk assessment exist? (give details of any previous risk assessment and its validity in relation to the risk assessment area)	A risk assessment for the European Union was conducted for the Bern Convention (Bertolino 2015) using an adapted GB UK non-native organism risk assessment (NNRA) scheme version 3.3. The final evaluation was: risk of entry: 4 (very likely), risk of establishment: 4 (very likely), risk of spread: 2 (moderate), impacts: 2 (moderate). Furthermore, Dijkstra and Dekker (2008) made a risk assessment for several species of exotic squirrels in the Netherlands. Although in general *Callosciurus* are popular (Dijkstra and Dekker 2009), trade and keeping of *C. finlaysonii* (subspecies *bocourti* and *ferrugineus*) was relatively limited in The Netherlands. Dijkstra and Dekker (2008) did not assess the risk associated with their introduction. There is no mention of subsequent observations of *C. finlaysonii* in the wild (Dijkstra &

	Dekker 201 2). In Belgium, an impact assessment was performed using the Invasive Species Ecological Impact Assessment (ISEIA) protocol guidelines (Branquart 2007; Branquart et al. 2009; Vanderhoeven et al. 2015). In Belgium the species was categorized as an alert list species with the ecological impact assessment protocol ISEIA (http://ias.biodiversity.be/species/show/127) (11 out of maximum score of 12), as it scored high on establishment potential and dispersal into natural habitats. In Germany, the species was assessed in the Grey List of potentially invasive species (Rabitsch et al. 2013). The results of the present study, which in fact builds on the risk assessment made for the Bern Convention by Bertolino (2015), are fully consistent with the assessments mentioned above.
A4. Where is the organism native?	The species is native to South East Asia, from central Myanmar, Thailand, Laos and Cambodia to Vietnam (Moore & Tate 1965; Wilson & Reeder 2005; Duckworth et al. 2008). Many subspecies only occur on isolated islands. Of the 16 subspecies, 12 are distributed in Thailand, making this the main distribution area (Boonkhaw et al. 2017).  Native range of *C. finlaysonii* (Duckworth et al. 2008) showing selection of records used for the species distribution model (see ANNEX VI - Species Distribution Model).

A5. What is the global non-native distribution of the organism outside the risk assessment area?	*Callosciurus finlaysonii* was introduced to Singapore and the Philippines (Bertolino & Lurz 2013). Some of the animals present at Hamamatsu (Japan), previously considered to be *C. erythraeus*, in fact carried mtDNA of *C. finlaysonii* (Oshida et al. 2007). The introduction of *C. finlaysonii* to Japan was confirmed by further work by Kuramoto et al. (2012). Gabrielli et al. (2014) provide data on C. *erythraeus* introduced to Argentina and whose haplotype was phylogenetically closer to sequences of *C. finlaysonii* (cf., Oshida et al. 2007).
A6. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species been recorded and where is it established?	The species has been reported and is established in the Continental and Mediterranean bioregions.
A7. In which biogeographic region(s) or marine subregion(s) in the risk assessment area could the species establish in the future under current climate and under foreseeable climate change?	Under current climatic conditions the Mediterranean bioregion is predicted by the species distribution model to be suitable for establishment. Under moderate (RCP4.5) and extreme (RCP8.5) emission scenarios, by 2070, the potential area for establishment is predicted to increase with the Atlantic, Continental and Black sea regions becoming suitable. It should be noted, however, that all current European records of the species are outside climatic boundaries of its subtropical native range (see Annex VI), indicating an adaptability of the species probably not fully captured by the model. Based on the species distribution model (Annex VI), the most limiting factors for establishment in northern part of Europe are cold winters. In the Mediterranean, according to the model, the main limiting factor is precipitation (drought). The species distribution model assumed areas which were colder and drier than the current occurrences were unsuitable for the species i.e. areas with a mean temperature of the warmest quarter (Bio10) below 19°C or with a minimum temperature of the coldest month (Bio6) below -1°C or a minimum annual precipitation (Bio12) of less than 600mm per year. There are considerable uncertainties around model predictions due to limited information on the species eco-physiological requirements and the known adaptability of the species to climatic conditions different from its subtropical native range. As the squirrels are mobile and the species could adapt, it can be expected that it could colonise areas predicted as unsuitable. For details on the assumptions made in relation to climate change see Annex VI: projection of climatic suitability.
A8. In which EU member states has the species been recorded and in which EU member states has it established? List them with an indication of the timeline of observations.	The species has only been recorded in Italy where populations are established. Two populations exist in northern and southern Italy. It was introduced in Piedmont (Acqui Terme, Alessandria) and Basilicata (Maratea) in the 1980s (Martinoli et al., 2010; Bertolino and Lurz,2013). Currently it is localized in Piedmont and widespread in Campania, Basilicata, and Calabria (Loy 2019). In the North, the species is established in and around an urban park within the city of Acqui Terme (Bertolino et al. 1999), following the release of two pairs in 1981 (Bertolino & Lurz 2013). Meawhile, there have been several sightings of *C. finlaysonii* outside Aqui Terme urban area in 2014-2015 (data E. Mori) and in 2020 (data P. Rizzola). In the South, *C. finlaysonii* was introduced in the mid-1980s through a release of 3-4 pairs (Aloise & Bertolino 2005). Initially, it remained restricted to an urban area, but after this initial lag-phase it later

	rapidly spread along the Tyrrhenian coast in both directions (south and north) along an area that stretched over 19 km of coastline in 2004 (Aloise & Bertolino 2005). This increased to 45 km in 2004 (Aloise & Bertolino 2008; Aloise et al. 2010). The total colonized area was 26 km^2 in 2005 (Aloise & Bertolino 2005) and increased to about 68 km^2 in 2008 (Aloise et al. 2010). Currently (2018), the area of occupancy in Italy is estimated at 580 km^2 based on a minimum convex polygon around known records (Bertolino & Di Febbraro unpublished data). It occurs at a maximum altitude of 841 m a.s.l. A recent study concluded that climate change will drive a further range increase in Italy, irrespectively of the alterations in land-use variables (Di Febbraro et al. 2019).  Current (2018) distribution of *C. finlaysonii* in Italy.
A9. In which EU member states could the species establish in the future under current climate and under foreseeable climate change?	Under current climatic conditions a number of Mediterranean EU Member States are predicted to be suitable for establishment: Italy, Spain, Croatia and Greece, potentially also Malta and Cyprus. Under a moderate (RCP4.5) emission scenario, by 2070, the potential area for establishment is predicted to increase with a number of EU Member States in the Atlantic and Continental bioregion such as Portugal and France. In an extreme (RCP8.5) emission scenario large parts of northwest Europe in Belgium, The Netherlands, Luxembourg, Germany and the southern part of Great Britain are predicted as suitable for the species establishment. See Question A7 or Annex VI for more details on the distribution model.

A10. Is the organism known to be invasive (i.e. to threaten or adversely impact upon biodiversity and related ecosystem services) anywhere outside the risk assessment area?	Data on the ecological impact of the species are scarce and scientific studies are still lacking. *Callosciurus finlaysonii* is considered a frequent predator of bird eggs in its native range (Bertolino & Lurz 2013). Data on damage are known only from Italy in the risk assessment area (Bertolino et al. 2004; Mori et al. 2016).
A11. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species shown signs of invasiveness?	Mediterranean, Continental
A12. In which EU member states has the species shown signs of invasiveness?	Italy
A13. Describe any known socio-economic benefits of the organism.	The species is kept, bred, exchanged and traded as a pet in Europe (European Pet Organisation 2018) thus represents aesthetic and economic values. The typical price per individual animal is in the region of 200-250 euros (European Pet Organization 2018). It is also kept in zoos, wildlife parks, animal rehabilitation centres and private collections, but it is probably an uncommon species (see question 1.4b). Animals are usually on display for a price of about 50 euros. More information on trade can be found in question 1.4a.

SECTION B – Detailed assessment

Important instructions:

- In the case of lack of information the assessors are requested to use a standardized answer: "No information has been found."
- The classification of pathways developed by the Convention of Biological Diversity shall be used For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document[8] and the provided key to pathways[9].
- With regard to the scoring of the likelihood of events or the magnitude of impacts see Annexes I and II.
- With regard to the confidence levels, see Annex III.

PROBABILITY OF INTRODUCTION and ENTRY

Important instructions:

- Introduction is the movement of the species into the risk assessment area.
- Entry is the release/escape/arrival in the environment, i.e. occurrence in the wild. Not to be confused with spread, the movement of an organism within the risk assessment area.
- For organisms which are already present in the risk assessment area, only complete this section for current active or if relevant potential future pathways. This section need not be completed for organisms which have entered in the past and have no current pathway of introduction and entry.

QUESTION	RESPONSE [chose one entry, delete all others]	CONFIDENCE [chose one entry, delete all others]	COMMENT
1.1. How many active pathways are relevant to the potential introduction of this organism? (If there are no active pathways or potential future pathways respond N/A and move to the Establishment section)	few	medium	Active pathways include escapes from zoos, (private) wildlife collections, pet shops etc. and the release of (pet) animals into the environment. Human assistance may amplify the potential of the species spread after first introduction as is illustrated by at least two reported translocations (i.e. deliberate capture, transportation and

[8] https://circabc.europa.eu/sd/a/738e82a8-f0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf

[9] https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf

			release of animals, Aloise & Bertolino 2005; Aloise et al. 2010).
1.2. List relevant pathways through which the organism could be introduced. Where possible give detail about the specific origins and end points of the pathways as well as a description of any associated commodities. For each pathway answer questions 1.3 to 1.10 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 1.3a, 1.4a, etc. and then 1.3b, 1.4b etc. for the next pathway.	Release in nature – Landscape/flora/ fauna "improvement" in the wild Escape from confinement – Botanical garden/zoo/aquaria		
Pathway name:	**Release in nature – Landscape/flora/ fauna "improvement" in the wild**		
1.3a. Is introduction along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)? (if intentional, only answer questions 1.4, 1.9, 1.10, 1.11 – delete other rows)	intentional	high	The species has been intentionally released in nature or parks for aesthetic reasons. This has been the main pathway of *C. finlaysonii* introductions in Italy (Bertolino et al. 1999; Aloise & Bertolino 2005). Squirrels are often released in or near urban areas such as parks, where they benefit from supplementary feeding.
1.4a. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year? Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.	moderately likely	low	In the absence of trade statistics, an internet survey was conducted between the 17th-21st January 2015, in order to investigate whether individuals of *C. finlaysonii* appeared to be traded within the EU, and whether there was a demand for these species as pets. The procedure was similar to the one used by UNEP-WCMC (2010) for *C. erythraeus* and *S. niger*. Adverts for the sale of *C. finlaysonii* were found on websites from Spain, Italy, Germany and The Netherlands. There were several advertisements for people wanting squirrels in general and also looking specifically for *C. finlaysonii*. Considering the inclusion of other exotic squirrel species (*C. erythraeus*, *S. carolinensis*, *S. niger*) in Regulation (EU) 1143/2014 which ban those species from the pet-trade, there is the possibility that the trade of *C.*

			finlaysonii could increase in the future.
1.9a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	likely	high	The species is often released in urban and suburban parks, which provides suitable habitat with supplemental feeding which can increase survival in the initial establishment phase (Bertolino et al. 1999; Aloise & Bertolino 2005; Bertolino & Lurz 2013). From here the species can spread to more natural habitats (Aloise & Bertolino 2005).
1.10a. Estimate the overall likelihood of entry into the risk assessment area based on this pathway?	likely	high	This pathway includes deliberate releases by pet owners which are the result of intentional introduction. The species is already present in Italy and is traded in other European countries (European Pet Organisation 2018). The main pathway of *C. finlaysonii* introductions in Italy has been releases of pet animals (Bertolino et al. 1999; Aloise & Bertolino 2005). Human assistance may amplify the potential of the species spread as is illustrated by at least two reported translocations (Aloise & Bertolino 2005; Aloise et al. 2010). These squirrels are appealing to humans, which can promote the spread of the species with translocation from one area to another. This is exemplified by *C. finlaysonii* in Southern Italy (Aloise & Bertolino 2005; Aloise et al. 2010), *C. erythraeus* in Argentina (Guichón et al. 2005, 2015) and Japan (Miyamoto et al. 2004), *S. carolinensis* in Italy (Martinoli et al. 2010; Signorile et al. 2016) and United Kingdom (Shorten 1954; Signorile et al. 2016), and with *S. stramineus* in Perù (Jessen et al. 2010). Translocations potentially create new propagules and could help the species to overcome geographical or ecological barriers, and increase the spread rate. The deliberate release of animals from captivity (see as a pathway example the video on YouTube regarding an illegal release of a chipmunk (http://www.youtube.com/watch?v=p_Ee4Bvk-eU) is probably the primary pathway of entry. As long as the species continues to be kept in captivity and is sold by pet shops the probability of releases remains (Bertolino

			2009; d'Ovidio et al. 2014; see point 1.4a). On top of that, established wild populations could be the source of animals for new introductions (Aloise & Bertolino 2005; Aloise et al. 2010) or for an illegal trade of the species (Signorile et al. 2016).
Pathway name:	**Escape from confinement – Botanical garden/zoo/aquaria**		
1.3b. Is introduction along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)? (if intentional, only answer questions 1.4, 1.9, 1.10, 1.11 – delete other rows)	unintentional	high	This pathway refers to escaped *C. finlaysonii* from facilities such as zoological gardens where wild animals are confined within enclosures (or live in semi-wild conditions), are displayed to the public, and in which they may also breed. It is different from the pet pathway in so far as the animals are typically on display to the general public (IUCN 2017). *Callosciurus finlaysonii* is arboreal and thus a good climber. It will be able to escape from a damaged or inadequately secured enclosure, as has been the case with other species of tree squirrels (*C. erythraeus*) and red squirrel *S. vulgaris* in Europe (e.g. Shuttleworth et al. 2014; Adriaens et al. 2015; Dijkstra & La Haye 2017).
1.4b. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year? Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.	unlikely	medium	Whilst there is no data available on the total population within all zoological collections within the EU, information was provided by EAZA (European Association of Zoos and Aquaria) on populations kept at approximately 300 of their Member zoos and aquariums in 26 EU Member States (with the exception of Cyprus and Malta). The information provided by EAZA (EAZA, 2018 personal communications) indicates the species is not kept by EAZA Member zoos/aquariums. In France *C. finlaysonii* was censused in only one zoo near Bordeaux (https://www.fermeexotique.fr/details-ecureuil+de+finlayson-167.html) that is not affiliated to the Association Francaise Des Parcs Zoologiques (AFDPZ) (personal communication J.-F. Maillard, survey ONCFS 2017). According to http://www.zootierliste.de/

			the species is at least on display in the Netherlands (Elten-Leur), France (Cadaujac), Russia and the United Kingdom. Unintentional escapes of native red squirrels *S. vulgaris* from woodland enclosures have been documented (e.g. after storm damage to the enclosures) indicating squirrel escapes are likely to happen despite the animals being properly housed (Shuttleworth et al. 2014). The European Pet Organization (2018) confirms the species is kept as a pet in private collections and zoological gardens. They indicate the species is both bred (in captivity) and exchanged within the hobbyist community but quantitative data on the numbers within the EU are lacking.
1.5b. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	likely	high	It is likely that the organism would survive along this pathway because generally animals kept in zoos are in good condition.
1.6b. How likely is the organism to survive existing management practices during passage along the pathway?	likely	high	As there are no relevant management practices for squirrels we score likely with high confidence.
1.7b. How likely is the organism to enter the risk assessment area undetected?	moderately likely	medium	The species could be confused by people without experience with the native Eurasian red squirrel and therefore not be reported (see A2), and sometimes the species are even confused in trade. Specific surveillance (e.g. wildlife camera trapping networks, surveillance with hair tubes cf. Ancillotto et al. 2018) is largely lacking. However, where such a surveillance exists, the entry of *Callosciurus* squirrels through this pathway has been recently documented. Information gathered under the LIFE U-SAVEREDS Project in 2017-2018 confirmed the presence of *C. prevostii* and *C. nigrovittatus* in Mestre (Venezia, Northern Italy – surveys implemented by the Venice Natural History

			Museum, M. Bon, personal communication) and the overall evaluation of sighting data allowed to conclude that the observed animals probably escaped from confinement.
1.8b. How likely is the organism to arrive during the months of the year most appropriate for establishment?	moderately likely	low	There is not a specific season in which C. *finlaysonii* is more likely to escape. However, animals that escape during late spring, summer or early autumn are likely to be successful in their survival and reproduction, since those seasons have the most favorable conditions weather and foodwise.
1.9b. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	Likely	medium	Zoos are often located in urban areas and similar to the pathway above, it is likely that escaped animals survive in parks, gardens etc. Medium confidence because little information is available on where exactly zoos are located that have C. *finlaysonii*.
1.10b. Estimate the overall likelihood of entry into the risk assessment area based on this pathway?	moderately likely	medium	Probably escapes happen but such events are rather rare as keeping the animals captive is in the interest of the zoos. However, Shuttleworth et al. (2014) report escapes of red squirrels *S. vulgaris* from mesh wire woodland enclosures in a captive zoological red squirrel collection, confirming that escapes are always possible even when squirrels are properly housed. As an illustration, red squirrel escaped from a Wildwood Trust in Herne Common (Kent, UK) during Storm Ciara in February 2020 (https://www.kentonline.co.uk/herne-bay/news/extinct-red-squirrel-running-wild-in-kent-222129/) and there are many more cases of escapes from zoos - often without subsequent recapture – of red squirrels reported in the UK (personal communication Craig Shuttleworth, 4/03/2020). Also, populations of the congeneric species *C. erythraeus* in the Netherlands, Belgium and Italy originated from escaped animals (e.g. Adriaens et al. 2015; Dijkstra & La Haye 2017). A low confidence has been given because of lack of information as to how many animals

			are actually kept in the RA area which makes it difficult to estimate the overall likelihood.
Pathway name:	**Escape from confinement – Pet / aquarium / terrarium species (including live food for such species)**		
1.3c. Is introduction along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)? (if intentional, only answer questions 1.4, 1.9, 1.10, 1.11 – delete other rows)	unintentional	high	This pathway refers to escaped *C. finlaysonii* from confinement or from controlled environments where they were kept by private collectors or hobbyists for recreation, enjoyment, companionship and/or trading (e.g. breeding/cultivation for sale to other collectors) (IUCN 2017). It also includes escapes from pet shops.
1.4c. How likely is it that large numbers of the organism will travel along this pathway from the point(s) of origin over the course of one year? Subnote: In your comment discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.	Likely	medium	The species is present in trade but even low numbers of animals can already represent a risk of establishment (see Q1.24).
1.5c. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	moderately likely	medium	It is likely that the organism would survive along this pathway because generally animals kept in collections are in good condition.
1.6c. How likely is the organism to survive existing management practices during passage along the pathway?	Likely	medium	As there are no relevant management practices for squirrels we score likely with high confidence.
1.7c. How likely is the organism to enter the risk assessment area undetected?	Likely	medium	See Qu. 1.7b.
1.8c. How likely is the organism to arrive during the months of the year most appropriate for establishment?	moderately likely	low	See Qu. 1.8b.
1.9c. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host?	Likely	medium	A lot of people live in urban areas, so it is likely that escaped animals will find parks or gardens to survive. They could also survive in forests close to the house that they escaped from.
1.10c. Estimate the overall likelihood of entry into the risk	moderately likely	low	

assessment area based on this pathway?			
End of pathway assessment, repeat as necessary.			
1.11. Estimate the overall likelihood of entry into the risk assessment area based on all pathways and specify if different in relevant biogeographical regions in current conditions (comment on the key issues that lead to this conclusion).	Likely	high	See comments 1.10a and 1.10b
1.12. Estimate the overall likelihood of entry into the risk assessment area based on all pathways in foreseeable climate change conditions?	Likely	high	Climate change is not expected to influence the likelihood of entry into the RA area, which therefore remains likely.

PROBABILITY OF ESTABLISHMENT

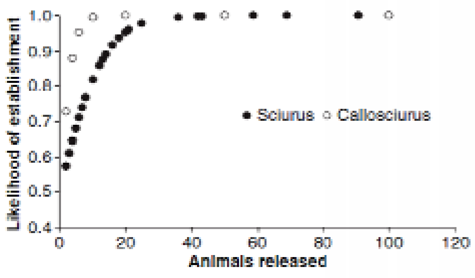
Important instructions:

- For organisms which are already established in parts of the risk assessment area, answer the questions with regard to those areas, where the species is not yet established. If the species is established in all Member States, continue with Question 1.16.

QUESTION	RESPONSE	CONFIDENCE	COMMENT
1.13. How likely is it that the organism will be able to establish in the risk assessment area based on the similarity between climatic conditions within it and the organism's current distribution?	moderately likely	medium	The species distribution model predicts suitable areas for establishment outside the current Italian range elsewhere in the Mediterranean based on several climatic variables. However, propagule pressure and human influence (e.g. supplemental feeding, urbanization, forest fragmentation) can be expected to contribute to this. As stated in Qu. A7, it should be noted that all current European records of the species are outside climatic boundaries of its subtropical native range (see Annex VI), indicating an adaptability of the species to overcome climatic constraints on its establishment and a degree of uncertainty on the species distribution model.
1.14. How likely is it that the organism will be able to establish in the risk assessment area based on the similarity between other abiotic conditions within it and the organism's current distribution?	likely	high	The species is adapted to urban and suburban areas, which are widespread in Europe (Aloise & Bertolino, 2005).
1.15. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in the risk assessment area?	widespread	high	In Europe the species is adapted to Mediterranean deciduous forests and Mediterranean pine forests and to urban and suburban areas (Bertolino et al. 2004; Aloise & Bertolino 2005; Rima et al., 2007). Such suitable habitats are present and widely distributed in Southern Europe. It feeds opportunistically and seasonally, mainly on plant matter, i.e. seeds, fruits,

			buds, flowers and sap, occasionally animal food including insects and bird eggs/nestlings. As stated in Qu. 1.13 and A7 it should be noted that all current European records of the species are outside climatic boundaries of its subtropical native range (see Annex VI), indicating an adaptability of the species probably not fully captured by the model.
1.16. If the organism requires another species for critical stages in its life cycle then how likely is the organism to become associated with such species in the risk assessment area ?	NA	NA	No other species is vital for the species survival, development or reproduction.
1.17. How likely is it that establishment will occur despite competition from existing species in the risk assessment area?	likely	high	As seen in the introduction areas around the world and in Italy in particular, competition for natural resources with existing species will not limit the establishment in the risk assessment area. The only other arboreal Sciurid that occupies the same ecological niche is the European red squirrel, which is not adapted to compete with members of its family. We scored likely since there are other *Callosciurus* species in its range which it could potentially compete with. In the native range, the two species are widely sympatric (Timmins and Duckworth 2008). However, this clearly did not hamper establishment in Italy (Di Febbraro et al. 2019).
1.18. How likely is it that establishment will occur despite predators, parasites or pathogens already present in the risk assessment area?	very likely	medium	Predators, parasites and pathogens present in Italy did not hinder the establishment of the species (Aloise & Bertolino 2005; Aloise et al. 2010).
1.19. How likely is the organism to establish despite existing management practices in the risk assessment area?	very likely	high	The species is very tolerant to forest fragmentation or woodland degradation, as observed in its native range (Duckworth et al. 2008).
1.20. How likely are existing management practices in the risk assessment area to facilitate establishment?	likely	high	The species is adaptable and can profit from urbanisation (supplemental feeding). As mentioned

			above, forest fragmentation could favour the establishment of the species.
1.21. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in the risk assessment area?	likely	medium	Finlasyson's squirrels have been removed with live-traps from a small area in Southern Italy (Ricciardi et al. 2013), but no details of the effects on the population are available. Experiences with other alien squirrels show that high removal rates are necessary to obtain success and that numbers return quickly to pre-control levels once killing is stopped e.g. where culling was localised and undisturbed adjacent populations were in close proximity in connected habitat patches (Lawton & Rochford 2007). Once established, squirrels are difficult if not impossible (with large populations) to eradicate though some success can be achieved at a local level with a high control effort (Schuchert et al. 2014). For instance, the grey squirrel was eradicated form an island of the size of the *C. finlaysonii* range in southern Italy (Schuchert et al. 2014). Also, in Belgium and the Netherlands, small populations of alien squirrels were successfully eradicated (Adriaens et al., 2015, Vane et al. 2016, Dijkstra & La Haye 2017).
1.22. How likely are the biological characteristics of the organism to facilitate its establishment in the risk assessment area?	likely	high	The species may establish from a very limited number of founders. As an illustration, established populations in Europe, Singapore and Japan originated from only a few animals (Bertolino 2009), thus proving the adaptability of *C. finlaysonii* to new habitats. Females can have two to three litters per year with 1-4 weaned young; varying percentage of adult females reproduce in a given season.
1.23. How likely is the adaptability of the organism to facilitate its establishment?	likely	high	Tree squirrels are considered particularly adaptable because of their relatively high reproductive potential, wide dietary range, and plasticity to anthropogenic habitats (Palmer et al. 2007, UNEP-

			WCMC 2010). In its native range it occurs in many habitats from primary and secondary forests to open woodland and plantations (Lurz 2014). It is very tolerant to woodland degradation and fragmentation (Duckworth et al. 2008). It is adaptable in its diet and habitat requirements
1.24. How likely is it that the organism could establish despite low genetic diversity in the founder population?	very likely	high	Tree squirrels are known to form viable populations from very few founders. The likelihood ratio for a pair of *Callosciurus* spp. (*C. erythraeus* and *C. finlaysonii* were considered) to successfully establish a viable population is 73% and a likelihood ratio of 90% is achieved from as little as 4 animals (Wood et al. 2007; Bertolino 2009).  Likelihood of *Sciurus* and *Callosciurus* establishment as a function of the number of animals released (Bertolino et al. 2009)
1.25. Based on the history of invasion by this organism elsewhere in the world, how likely is it to establish in the risk assessment area? (If possible, specify the instances in the comments box.)	very likely	high	The species has successfully established in Singapore and Japan and it is very likely to establish in the risk assessment area beyond the current Italian range.
1.26. If the organism does not establish, then how likely is it that casual populations will continue to occur? Subnote: Red-eared Terrapin, a species which cannot re-produce in GB but is present because of continual release, is	likely	low	The likelihood of this to happen would depend on the number of animals released/escaped. However, such non-reproducing animals in the wild are quite common in other squirrel species in Europe (high number of casual sightings of species like

an example of a transient species.			*Tamiasciurus hudsonicus*, *Callosciurus prevosti* etc.).
1.27. Estimate the overall likelihood of establishment in relevant biogeographical regions in current conditions (mention any key issues in the comment box).	likely	medium	*Callosciurus finlaysonii* originates from tropical and subtropical broadleaf forests in Asia. They have colonized the Continental bioregion in Northern Italy (Bertolino & Lurz 2013). This is supported by the species distribution model. Under current climatic conditions the Mediterranean bioregion is predicted to be suitable for establishment. Based on the species distribution model, the most limiting factors for establishment in the northern part of Europe are cold winters. In the Mediterranean, the main limiting factor is precipitation (drought). These factors could reflect thermal stress in the active/breeding season. The species distribution model assumed areas which were colder and drier than the current occurrences were unsuitable for the species i.e. areas with a mean temperature of the warmest quarter (Bio10) below 19°C or with a minimum temperature of the coldest month (Bio6) below -1°C or a minimum annual precipitation (Bio12) of less than 600mm per year. However, there are uncertainties around model predictions due to limited information on the species eco-physiological requirements and the adaptability of the species, i.e. all current European records of the species are outside climatic boundaries of its subtropical native range (see Annex VI), indicating an adaptability of the species not fully captured by the model. As the squirrels are mobile and the species is quite adaptive, it can be expected that it could also colonise areas predicted as unsuitable by the model. As an illustration, all current European records of the species are outside climatic boundaries of its

			subtropical native range. Besides climatic constraints, propagule pressure and human influence can also play a role in establishment success.
1.28. Estimate the overall likelihood of establishment in relevant biogeographical regions in foreseeable climate change conditions	likely	medium	Under moderate (RCP4.5) and extreme (RCP8.5) emission scenarios, by 2070, the potential area for establishment is predicted to increase to more northern regions with the Atlantic, Continental and Black sea region also becoming suitable. For more details on the SDM see questions A7, A9 or Annex VI. Also, Di Febbraro et al. (2019) note that in Italy the distribution of C. *finlaysonii* is primarily driven by climate and less by changes in land use.

PROBABILITY OF SPREAD

Important notes:

- Spread is defined as the expansion of the geographical distribution of an alien species within the risk assessment area.
- Repeated releases at separate locations do not represent spread and should be considered in the probability of introduction and entry section. In other words, intentional anthropogenic "spread" via release or escape should be dealt within the introduction and entry section.

QUESTION	RESPONSE	CONFIDENCE	COMMENT
2.1. How important is the expected spread of this organism within the risk assessment area by natural means? (Please list and comment on each of the mechanisms for natural spread.)	high	medium	In southern Italy *C. finlaysonii* has spread over an area of 581 km^2, after a lag-phase of more than 20 years. The dispersal capacity of *C. finlaysonii* seems to be high, mainly of immature individuals, which will colonize new areas. The species has spread along the Tyrrhenian coast in a few years in Mediterranean deciduous and pine forests and to urban and suburban areas (Bertolino et al. 2004; Aloise & Bertolino 2005; Rima et al. 2007). The Maratea population is in rapid expansion, not only in the coastal area, but also towards the interior, up to relatively high altitudes. Here, it potentially threatens the populations of the native *Sciurus meridionalis*, which is expanding northwards. The range of *C. finlaysonii* now also includes the southern part of the Cilento, Vallo di Diano and Alburni National Park (Alien Squirrel Emergency Team 2017).
2.2. How important is the expected spread of this organism within the risk assessment area by human assistance? (Please list and comment on each of the mechanisms for human-assisted spread) and provide a description of the associated commodities.	low	medium	
2.2a. List and describe relevant pathways of spread. Where	Unaided - Natural		Studies of dispersal distances are not available for this

possible give detail about the specific origins and end points of the pathways. For each pathway answer questions 2.3 to 2.9 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 2.3a, 2.4a, etc. and then 2.3b, 2.4b etc. for the next pathway.	dispersal across borders		squirrel species. The only data available relates to the spread in southern Italy where the species tripled its area of occupancy in four years and increased it by 8.5 times in ten years. The population in Southern Italy is rapidly spreading along the Tyrrhenian coast, having colonized an area of 26 km^2 by 2004 (Aloise & Bertolino 2005). Its range increased to 68 km^2 in 2008 (Aloise & Bertolino 2008; Aloise et al. 2010) and up to 581 km^2 by 2018. The population in Northern Italy is still present after thirty years since its initial introduction, though localised in an urban area and surroundings. In Singapore, the species is slowly spreading in the city (Benjamin Lee pers. comm.). In case of newly established populations in other countries, the spread rate could be from moderate to high, depending on the habitat.
Pathway name:	**Unaided - Natural dispersal across borders**		
2.3. Is spread along this pathway intentional (e.g. the organism is released at distant localities) or unintentional (the organism is a contaminant of imported goods)?	unintentional	high	Unaided natural dispersal across borders is unintentional
2.4. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year?	moderately likely	low	See 2.2a
2.5. How likely is the organism to survive during passage along the pathway (excluding management practices that would kill the organism)? Subnote: In your comment consider whether the organism could multiply along the pathway.	very likely	high	See 2.2a Active dispersal, mainly of immature individuals, which will colonize new areas of suitable habitat.
2.6. How likely is the organism to survive existing management practices during spread?	very likely	high	The species is spreading rapidly in Southern Italy, and remains present in Northern Italy after 30 years. The population in Singapore is steadily increasing.

2.7. How likely is the organism to spread in the risk assessment area undetected?	moderately likely	medium	The species is not easily recognisable from the native Eurasian red squirrel and specific surveillance (e.g. wildlife camera trapping networks, surveillance with hair tubes) is largely lacking. Therefore, local spread may be undetected. More information under 1.7b.
2.8. How likely is the organism to be able to transfer to a suitable habitat or host during spread?	likely	medium	*Callosciurus finlaysonii* is an adaptable species, occupying several types of forest, even fragmented or degraded forest, and urban areas, such as parks. It could also benefit from supplementary feeding in urban areas. We scored medium because at least in the northern Italian population spread seems limited.
2.9. Estimate the potential rate of spread within the Union based on this pathway (please provide quantitative data where possible)?	moderately	medium	Even though spread in Southern Italy is happening at a fast rate (see Q 2.11), this is not the case for the population in the north of the country (Ancillotto et al. 2018). The latter population is still concentrated within an urban area thirty years after its initial introduction. The lack of spread may be related to the introduction of only two pairs (3-4 pairs in the South) and/or to the difficulty to adapt to the habitats outside the city, where supplemental feeding by humans is lacking.
End of pathway assessment, repeat as necessary.			
2.10. Within the risk assessment area, how difficult would it be to contain the organism in relation to these pathways of spread?	difficult	medium	A control program was activated in Southern Italy, but results are not available yet (Ricciardi et al. 2013). From experience gained in Europe with other alien squirrels, the species could probably be contained where it does not spread over large areas, partly because of seasonally high trappability, and partly because of easy recognition of the species in new areas. However, practical difficulties are likely to arise because of diverse land ownership patterns in control areas with possible difficulties in access private property and because of potential public opposition to control/eradication (Barr et al. 2002; Rushton et al. 2002; Anonymous 2013).

2.11. Estimate the overall potential rate of spread in relevant biogeographical regions under current conditions for this organism in the risk assessment area (using the comment box to indicate any key issues and provide quantitative data where possible).	moderately	medium	Studies of dispersal distances are not available for this squirrel species. The only data available relates to the spread in southern Italy where the species tripled its area of occupancy in four years and increase it by 8.5 times in ten years. See also 2.2a.
2.12. Estimate the overall potential rate of spread in relevant biogeographical regions in foreseeable climate change conditions *(please provide quantitative data where possible)*	rapidly	low	Given that available suitable habitat for C. finlaysonii is expected to increase with climate change in the risk assessment area (see A8, Di Febbraro et al. 2019), the rate of spread might also increase.

MAGNITUDE OF IMPACT

Important instructions:

- Questions 2.13-2.17 relate to biodiversity and ecosystem impacts, 2.18-2.20 to impacts on ecosystem services, 2.21-2.25 to economic impact, 2.26-2.27 to social and human health impact, and 2.28-2.30 to other impacts. These impacts can be interlinked, for example a disease may cause impacts on biodiversity and/or ecosystem functioning that leads to impacts on ecosystem services and finally economic impacts. In such cases the assessor should try to note the different impacts where most appropriate, cross-referencing between questions when needed.
- Each set of questions starts with the impact elsewhere in the world, then considers impacts in the risk assessment area (=EU excluding outermost regions) separating known impacts to date (i.e. past and current impacts) from potential future impacts (including foreseeable climate change).
- Only negative impacts are considered in this section (socio-economic benefits are considered in Qu. A.7)

QUESTION	RESPONSE	CONFIDENCE	COMMENTS
Biodiversity and ecosystem impacts			
2.13. How important is impact of the organism on biodiversity at all levels of organisation caused by the organism in its non-native range excluding the risk assessment area?	minor	low	Data on the ecological impact of *C. finlaysonii* are scarce and proper studies are lacking. The species is considered a frequent predator of bird nests in its native range (Bertolino & Lurz 2013), but there is no information for the introduced range available (Bertolino et al. 2015). In its native range, *C. finlaysonii* is considered an important seed consumer and seed dispersal agent (Kitamura et al. 2004; Chanthorn et al. 2007; Suzuki et al. 2007).
2.14. How important is the current known impact of the organism on biodiversity at all levels of organisation (e.g. decline in native species, changes in native species communities, hybridisation) in the risk assessment area (include any past impact in your response)?	moderate	low	The activity of bark stripping typical of the species increases the risk of fungal infections and invertebrate damage on trees which can indirectly have an influence on associated woodland biota. There are some potential problems of predation on bird eggs/nestlings, but studies in the risk assessment area are missing and also from its native range there are only qualitative data available hence low confidence (Bertolino & Lurz 2013). Transmission of pathogens could likely cause a risk but there are no data available. Introduced populations of the

			related Pallas's squirrel in Europe were shown to host a number of co-introduced macroparasites such as lice and nematodes but these pathogen guilds were dominated by a few specialist taxa imported with the founders (Dozières et al. 2010). Dozières et al. (2010) consider those as minimal sanitary risks for both native fauna and humans in urbanized habitats where the animals were sampled.
2.15. How important is the potential future impact of the organism on biodiversity at all levels of organisation likely to be in the risk assessment area?	moderate	low	The potential impact on other species such as the red squirrel *S. vulgaris* and the Calabrian black squirrel *S. meridionalis*, woodland birds or dormouse (Gliridae) is unknown but possible, considering impacts by other alien squirrels introduced in Europe (i.e. *S. carolinensis*, *Tamias sibiricus*, *C. erythraeus*). Particularly, both *S. carolinensis* and *C. erythraeus* are already threatening local red squirrel populations through interspecific competition and disease transmission (Gurnell et al. 2004; Shuttleworth et al. 2016; Mazzamuto et al. 2017a,b). If bark stripping produced significant damage frequently, this could influence woodland management practices, with a shift away from trees susceptible to squirrel damage (Mayle 2005) (See 2.22), and with an impact on the flora and fauna associated with specific woodland types.
2.16. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism currently in the risk assessment area?	NA	NA	Current impact of *C. finlaysonii* on conservation assets is undocumented.
2.17. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism likely to be in the future in the risk assessment area?	moderate	low	Although not included in the Habitat Directive, the possible interference with the native red squirrel and the Calabrian black squirrel could decrease the conservation status of these species as well as many areas where they occur. Calabrian black squirrel, which was recently promoted to species level based on genetic studies, has a small range in the RA area and is endemic to the Calabrian mountains of southwestern Italy (Wauters et al.

			2017). The region is potentially suitable for establishment of *C. finlaysonii* and therefore the species could be impacted by this invader although it would probably not disappear entirely (hence moderate impact).
Ecosystem Services impacts			
2.18 How important is the impact of the organism on provisioning, regulating, and cultural services in its non-native range excluding the risk assessment area?	minimal	low	This has not been assessed in Singapore and Japan, although it can be assumed that this impact is minimal, especially in Singapore, given the small size of the population.
2.19. How important is the impact of the organism on provisioning, regulating, and cultural services currently in the different biogeographic regions or marine sub-regions where the species has established in the risk assessment area (include any past impact in your response)?	moderate	medium	The observed impacts of *C. finlaysonii* on ecosystem services are caused by bark stripping and seed dispersal. Bark stripping by *C. finlaysonii* has been observed in Italy (Bertolino et al. 2004; Aloise & Bertolino 2005; Mori et al. 2016). This can cause (secondary) infections in trees and has already led to the phytosanitary cutting of ornamental trees in Northern Italy (see 2.22). The species is also a seed disperser and could be a vector or host for pathogens. In natural forests, this could influence forest structure, species composition, the amount of (standing) dead wood, forest management practices etc. Given the above, impacts could occur on the following ecosystem services: provisioning – biomass – cultivated terrestrial plants, provisioning – biomass – wild plants, regulating services – regulation of physical, chemical, biological conditions - lifecycle maintenance (e.g. seed dispersal) and pest and disease control, as well as cultural – experiential interactions (due to phytosanitary cutting in urban green areas). These effects are probably rather local and reversible hence moderate impact.
2.20. How important is the impact of the organism on provisioning, regulating, and cultural services likely to be in the different biogeographic regions or marine sub-regions	major	low	Widespread but reversible impacts on several provisioning and regulating services in the future are possible if the species spreads in the risk assessment area

where the species can establish in the risk assessment area in the future?			(see 2.19).
Economic impacts			
2.21. How great is the overall economic cost caused by the organism within its current area of distribution (excluding the risk assessment area), including both costs of / loss due to damage and the cost of current management	NA	NA	No information available
2.22. How great is the economic cost of / loss due to damage* of the organism currently in the risk assessment area (include any past costs in your response)? *i.e. excluding costs of management	moderate	medium	In Italy the most evident damage caused by this species is bark stripping, which can cause (secondary) infections in trees and warrant phytosanitary cutting of 42 out of 308 ornamental deciduous trees. Damage can be considerable, yet is not quantified in economic terms. In Northern Italy, squirrels were observed eating plant matter, including bark and sap, seeds and fruits, buds and flowers; animal food included insects and insect honeydew. Bark stripping damage has been estimated to occur on 80% of the trees (11 species of deciduous and coniferous trees) in an urban park in the population in Northern Italy (Bertolino et al. 2004; Aloise & Bertolino 2005; Mori et al. 2016). In southern Italy, it has been estimated at a mean of 40% for nine wooded areas (Mori et al. 2016). Damage to electric cables and other infrastructure has also been reported (Aloise & Bertolino 2005; Aloise et al. 2010).
2.23. How great is the economic cost of / loss due to damage* of the organism likely to be in the future in the risk assessment area? *i.e. excluding costs of management	major	low	The damage through bark stripping and cable gnawing would be major if the species were not eradicated and was able to extend its range and invade other suitable areas in the RA area. Since quantified data on economic cost are not available confidence is low.
2.24. How great are the economic costs / losses associated with managing this organism currently in the risk assessment area (include any past costs in your response)?	moderate	low	Considering previous management programs on other squirrel species (e.g. grey squirrel, Pallas's squirrel) costs could be high (see question 2.25).
2.25. How great are the economic costs / losses associated with managing this organism likely to be in the future in the	major	medium	Considering previous management programs on other squirrel species (e.g. grey squirrel, Pallas's squirrel) future

risk assessment area?			control costs could be considerable. This can be inferred from control actions on the related Pallas's squirrel *C. erythraeus* in the RA area. Even rapid eradication from Belgium which included the permanent removal of 250 animals within a 5-year timeframe came at a considerable 200k€ cost including the cost of surveillance and post-eradication monitoring (Adriaens et al. 2015). A Pallas's squirrel invasion in The Netherlands (Weert) was tackled by rapid eradication at a cost of 330k€ to run the programme and remove 250 squirrels, but with the help of volunteers (pers. comm. M. La Haye; Dijkstra & Dekker 2012; Dijkstra 2013a,b). Costs are higher for established populations with a higher number of animals, such as in France where control actions for Pallas's squirrel were planned at about 100k€ per annum for the period 2011-2014 (Chapuis et al. 2011). Robertson et al. (2016) proposed a relationship between the area of invasive mammal eradications and their cost from previous eradication projects. According to this work, a mammal population spread over an area of around 1,000 km^2 could be eradicated with few millions US dollars. If the species is not banned from Europe, the possibility of new introductions is high and therefore further management actions will be needed. Control costs will then increase with every new case of an introduced, established and spreading population.
Social and human health impacts			
2.26. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism for the risk assessment area and for third countries, if relevant (e.g. with similar eco-climatic conditions).	minimal	low	*Callosciurus finlaysonii* sampled in pet stores in Italy tested positive for *Dicrocoelium dendriticum* (d'Ovidio et al. 2014) that could infect humans (Gualdieri et al. 2011; Jeandron et al. 2011). Several fungal diseases were found in animals culled in Southern Italy: *Cryptococcus neoformans*, *Debaryomyces hansenii*, *Meyerozyma*

			guilliermondii, *Hanseniaspora thailandica*. The latter species originated from the Indochinese area and was probably introduced in Italy with the squirrels (Iatta et al. 2015). However, no information is available on associated human health impact. A bornavirus associated with variegated squirrel *Sciurus variegatoides* was reported to have lethal zoonotic effects on three squirrel breeders of the same private squirrel-breeding association in Germany (Hoffman et al. 2015). However, all patients had pre-existing medical conditions. Although variegated squirrel bornavirus 1 (VSBV-1), associated with Sciurinae and Callosciurinae, was found in C. prevostii at a prevalence of 8.8% and can potentially be transmitted to humans through scratching or biting (Schlottau et al. 2017), it is unknown whether this virus is also prevalent in and/or transmissable by *C. finlaysonii*. Also, there needs to be direct contact for transmission to occur and this risk is probably low for populations in the wild. Bornavirus is mostly relevant for people handling squirrels (breeders, people managing squirrels) without taking precautionary measures. There is also the possibility for squirrels to be a reservoir of ticks carrying the Lyme disease spirochete Borrelia burgdorferi. For instance, Siberian ground squirrels are known to be potent reservoirs of lyme borreliosis (Marsot et al. 2011, 2013), and western grey squirrel Sciurus griseus, eastern grey squirrels S. carolinensis and fox squirrels S. niger were all identified as reservoir hosts of Lyme disease (Salkeld et al. 2008). However, no information was found on the role of *C. finlaysonii* (or *Callosciurus*) as a reservoir for Lyme disease.
2.27. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism in the future for the risk assessment area.	minimal	low	No information has been found on the issue.
Other impacts			

2.28. How important is the impact of the organism as food, a host, a symbiont or a vector for other damaging organisms (e.g. diseases)?	minimal	low	Alien tree squirrels have been linked to the introduction of novel parasites and diseases including the spread of zoonotic disease (e.g. Dozières et al. 2010; Bertolino & Lurz 2013; Romero et al. 2014, 2015). As an illustration, introduced populations of the related Pallas's squirrel in Europe were shown to host a number of co-introduced macroparasites such as lice and nematodes but these pathogen guilds were dominated by a few specialist taxa imported with the founders and were considered a minimal sanitary risks for both native fauna and humans in urbanized habitats where the animals were sampled (Dozières et al. 2010). Currently, data for *C. finlaysonii* are largely lacking, but the risk of disease transmission, and introduced individuals acting as vectors for parasites and diseases that can harm native wildlife (and potentially humans) should be considered (Lurz 2014). *Callosciurus finlaysonii* sampled in pet stores in Italy tested positive for *Dicrocoelium dendriticum* (d'Ovidio et al. 2014) that could infect humans (Gualdieri et al. 2011; Jeandron et al. 2011). Several fungal diseases were found in animals culled in Southern Italy: *Cryptococcus neoformans*, *Debaryomyces hansenii*, *Meyerozyma guilliermondii*, *Hanseniaspora thailandica.* The latter species originated from the Indochinese area and was probably introduced in Italy with the squirrels (Iatta et al. 2015). The species could probably be preyed on by many mammals and raptors, but there are no data available in the literature on the species that could effectively prey on them and possible effects.
2.29. How important might other impacts not already covered by previous questions be resulting from introduction of the organism? (specify in the comment box)	minimal	low	No other impacts documented.
2.30. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already	major	medium	Data from the native range are missing. Predators, parasites and pathogens present in Italy did not limit the spread of the species (Aloise & Bertolino 2005; Aloise et

be present in the risk assessment area?			al. 2010).

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ANNEX I Scoring of Likelihoods of Events

(taken from UK Non-native Organism Risk Assessment Scheme User Manual, Version 3.3, 28.02.2005)

Score	**Description**	**Frequency**
Very unlikely	This sort of event is theoretically possible, but is never known to have occurred and is not expected to occur	1 in 10,000 years
Unlikely	This sort of event has not occurred anywhere in living memory	1 in 1,000 years
moderately likely	This sort of event has occurred somewhere at least once in recent years, but not locally	1 in 100 years
Likely	This sort of event has happened on several occasions elsewhere, or on at least one occasion locally in recent years	1 in 10 years
Very likely	This sort of event happens continually and would be expected to occur	Once a year

ANNEX II Scoring of Magnitude of Impacts

(modified from UK Non-native Organism Risk Assessment Scheme User Manual, Version 3.3, 28.02.2005)

Score	**Biodiversity and ecosystem impact**	**Ecosystem Services impact**	**Economic impact (Monetary loss and response costs per year)**	**Social and human health impact**
	Question 2.18-22	*Question 2.23-25*	*Question 2.26-30*	*Question 2.31-32*
Minimal	Local, short-term population loss, no significant ecosystem effect	No services affected[10]	Up to 10,000 Euro	No social disruption. Local, mild, short-term reversible effects to individuals.
Minor	Some ecosystem impact, reversible changes, localised	Local and temporary, reversible effects to one or few services	10,000-100,000 Euro	Significant concern expressed at local level. Mild short-term reversible effects to identifiable groups, localised.
Moderate	Measureable long-term damage to populations and ecosystem, but little spread, no extinction	Measureable, temporary, local and reversible effects on one or several services	100,000-1,000,000 Euro	Temporary changes to normal activities at local level. Minor irreversible effects and/or larger numbers covered by reversible effects, localised.
Major	Long-term irreversible ecosystem change, spreading beyond local area	Local and irreversible or widespread and reversible effects on one / several services	1,000,000-10,000,000 Euro	Some permanent change of activity locally, concern expressed over wider area. Significant irreversible effects locally or reversible effects over large area.
Massive	Widespread, long-term population loss or extinction, affecting several species with serious ecosystem effects	Widespread and irreversible effects on one / several services	Above 10,000,000 Euro	Long-term social change, significant loss of employment, migration from affected area. Widespread, severe, long-term, irreversible health effects.

[10] Not to be confused with „no impact“.

ANNEX III Scoring of Confidence Levels

(modified from Bacher *et al.*. 2017)

Confidence level	**Description**
Low	There is no direct observational evidence to support the assessment, e.g. only inferred data have been used as supporting evidence *and/or* Impacts are recorded at a spatial scale which is unlikely to be relevant to the assessment area *and/or* Evidence is poor and difficult to interpret, e.g. because it is strongly ambiguous *and/or* The information sources are considered to be of low quality or contain information that is unreliable.
Medium	There is some direct observational evidence to support the assessment, but some information is inferred *and/or* Impacts are recorded at a small spatial scale, but rescaling of the data to relevant scales of the assessment area is considered reliable, or to embrace little uncertainty *and/or* The interpretation of the data is to some extent ambiguous or contradictory.
High	There is direct relevant observational evidence to support the assessment (including causality) *and* Impacts are recorded at a comparable scale *and/or* There are reliable/good quality data sources on impacts of the taxa *and* The interpretation of data/information is straightforward *and/or* Data/information are not controversial or contradictory.

ANNEX IV Ecosystem services classification (CICES V5.1, simplified) and examples

For the purposes of this risk assessment, please feel free to use what seems as the most appropriate category / level / combination of impact (Section – Division – Group), reflecting information available.

Section	Division	Group	Examples (i.e. relevant CICES "classes")
Provisioning	**Biomass**	**Cultivated *terrestrial* plants**	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes; Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials); Cultivated plants (including fungi, algae) grown as a source of energy *Example: negative impacts of non-native organisms to crops, orchards, timber etc.*
		Cultivated *aquatic* plants	Plants cultivated by in- situ aquaculture grown for nutritional purposes; Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials); Plants cultivated by in- situ aquaculture grown as an energy source. *Example: negative impacts of non-native organisms to aquatic plants cultivated for nutrition, gardening etc. purposes.*
		Reared animals	Animals reared for nutritional purposes; Fibres and other materials from reared animals for direct use or processing (excluding genetic materials); Animals reared to provide energy (including mechanical) *Example: negative impacts of non-native organisms to livestock*
		Reared *aquatic* animals	Animals reared by in-situ aquaculture for nutritional purposes; Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials); Animals reared by in-situ aquaculture as an energy source *Example: negative impacts of non-native organisms to fish farming*
		Wild plants (terrestrial and aquatic)	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition; Fibres and other materials from wild plants for direct use or processing (excluding genetic materials); Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy *Example: reduction in the availability of wild plants (e.g. wild berries, ornamentals) due to non-native organisms (competition, spread of disease etc.)*

		Wild animals (terrestrial and aquatic)	Wild animals (terrestrial and aquatic) used for nutritional purposes; Fibres and other materials from wild animals for direct use or processing (excluding genetic materials); Wild animals (terrestrial and aquatic) used as a source of energy *Example: reduction in the availability of wild animals (e.g. fish stocks, game) due to non-native organisms (competition, predations, spread of disease etc.)*
	Genetic material from all biota	**Genetic material** from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population; Higher and lower plants (whole organisms) used to breed new strains or varieties; Individual genes extracted from higher and lower plants for the design and construction of new biological entities *Example: negative impacts of non-native organisms due to interbreeding*
		Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population; Wild animals (whole organisms) used to breed new strains or varieties; Individual genes extracted from organisms for the design and construction of new biological entities *Example: negative impacts of non-native organisms due to interbreeding*
	Water[11]	**Surface water** used for nutrition, materials or energy	Surface water for drinking; Surface water used as a material (non-drinking purposes); Freshwater surface water, coastal and marine water used as an energy source *Example: loss of access to surface water due to spread of non-native organisms*
		Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking; Ground water (and subsurface) used as a material (non-drinking purposes); Ground water (and subsurface) used as an energy source *Example: reduced availability of ground water due to spread of non-native organisms and associated increase of ground water consumption by vegetation.*
Regulation & Maintenance	**Transformation** of biochemical or physical inputs to ecosystems	**Mediation of wastes or toxic substances** of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals; Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals *Example: changes caused by non-native organisms to ecosystem functioning and ability to filtrate etc. waste or toxics*
		Mediation of nuisances of anthropogenic origin	Smell reduction; noise attenuation; visual screening (e.g. by means of green infrastructure) *Example: changes caused by non-native organisms to ecosystem structure, leading to reduced ability to mediate nuisances.*

[11] Note: in the CICES classification provisioning of water is considered as an abiotic service whereas the rest of ecosystem services listed here are considered biotic.

	Regulation of physical, chemical, biological conditions	**Baseline flows and extreme event** regulation	Control of erosion rates; Buffering and attenuation of mass movement; Hydrological cycle and water flow regulation (Including flood control, and coastal protection); Wind protection; Fire protection *Example: changes caused by non-native organisms to ecosystem functioning or structure leading to, for example, destabilisation of soil, increased risk or intensity of wild fires etc.*
		Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context); Seed dispersal; Maintaining nursery populations and habitats (Including gene pool protection) *Example: changes caused by non-native organisms to the abundance and/or distribution of wild pollinators; changes to the availability / quality of nursery habitats for fisheries*
		Pest and disease control	Pest control; Disease control *Example: changes caused by non-native organisms to the abundance and/or distribution of pests*
		Soil quality regulation	Weathering processes and their effect on soil quality; Decomposition and fixing processes and their effect on soil quality *Example: changes caused by non-native organisms to vegetation structure and/or soil fauna leading to reduced soil quality*
		Water conditions	Regulation of the chemical condition of freshwaters by living processes; Regulation of the chemical condition of salt waters by living processes *Example: changes caused by non-native organisms to buffer strips along water courses that remove nutrients in runoff and/or fish communities that regulate the resilience and resistance of water bodies to eutrophication*
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans; Regulation of temperature and humidity, including ventilation and transpiration *Example: changes caused by non-native organisms to ecosystems' ability to sequester carbon and/or evaporative cooling (e.g. by urban trees)*
Cultural	**Direct, in-situ and outdoor interactions** with living systems that depend on presence in the environmental	**Physical and experiential** interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions; Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions

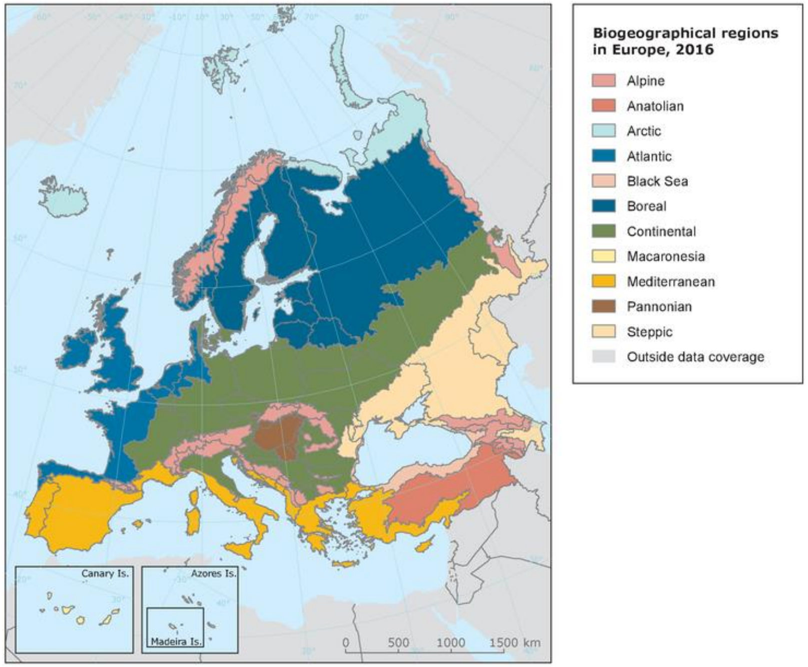
	setting		*Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that make it attractive for recreation, wild life watching etc.*
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge; Characteristics of living systems that enable education and training; Characteristics of living systems that are resonant in terms of culture or heritage; Characteristics of living systems that enable aesthetic experiences *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have cultural importance*
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	**Spiritual, symbolic** and other interactions with natural environment	Elements of living systems that have symbolic meaning; Elements of living systems that have sacred or religious meaning; Elements of living systems used for entertainment or representation *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have sacred or religious meaning*
		Other biotic characteristics that have a **non-use value**	Characteristics or features of living systems that have an existence value; Characteristics or features of living systems that have an option or bequest value *Example: changes caused by non-native organisms to ecosystems designated as wilderness areas, habitats of endangered species etc.*

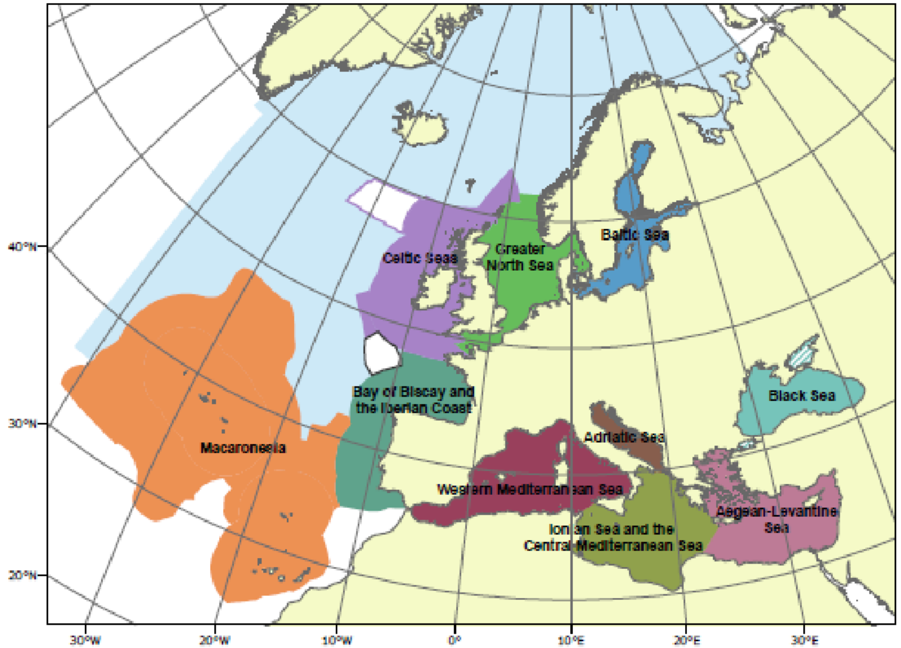
ANNEX V EU Biogeographic Regions and MSFD Subregions

See https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2 , http://ec.europa.eu/environment/nature/natura2000/biogeog_regions/

and

https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions-1/technical-document/pdf





ANNEX VI - Species Distribution Model

Daniel Chapman - 20th May 2018

Aim

To project the climatic suitability for potential establishment of *Callosciurus finlaysonii* in Europe, under current and predicted future climatic conditions.

Data for modelling

Species occurrence data were obtained from the Global Biodiversity Information Facility (GBIF), VertNet, iNaturalist, iDigBio, and from a database of Italian occurrences (Sandro Bertolino, *pers. comm.*). We scrutinised occurrence records from regions where the species is not known to be established and removed any that appeared to be dubious or where the georeferencing was too imprecise (e.g. records referenced to a country or island centroid) or outside of the coverage of the predictor layers (e.g. small island or coastal occurrences). The remaining records were gridded at a 0.25 x 0.25 degree resolution for modelling (Figure 1a). This resulted in a total of only 58 grid cells containing records of *C. finlaysonii* for the modelling (Figure 1a), which is a very low number for distribution modelling.

Climate data were taken from 'Bioclim' variables contained within the WorldClim database (Hijmans et al., 2005) originally at 5 arcminute resolution (0.083 x 0.083 degrees of longitude/latitude) and aggregated to a 0.25 x 0.25 degree grid for use in the model. Consideration of the likely limiting factors on establishment in Europe led to selection of the following climate variables were used in the modelling:

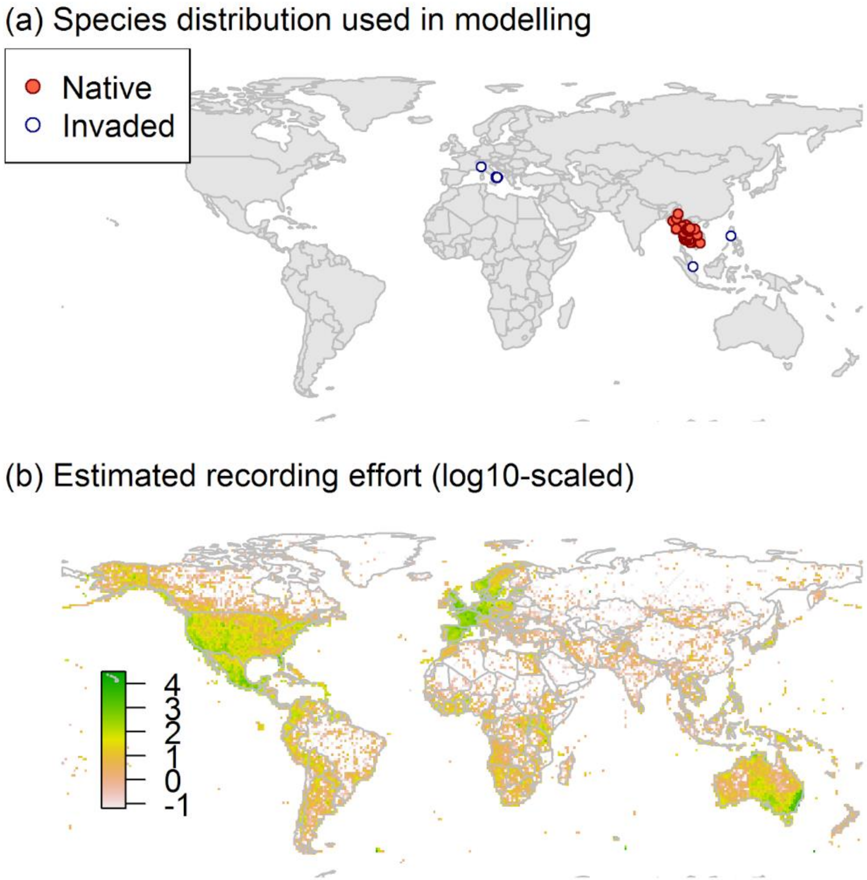
- Minimum temperature of the coldest month (Bio6 °C) reflecting winter cold stress.
- Mean temperature of the warmest quarter (Bio10 °C) reflecting the summer thermal regime.
- Annual precipitation (mm, log+1 transformed) reflecting moisture availability.

To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for the 2070s under the Representative Concentration Pathway (RCP) 4.5 and 8.5 were also obtained. For both scenarios, the above variables were obtained as averages of outputs of eight Global Climate Models (BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, IPSL-CM5A-LR, MIROC-ESM, MRI-CGCM3, NorESM1-M), downscaled and calibrated against the WorldClim baseline (see http://www.worldclim.org/cmip5_5m).

RCP 4.5 is a moderate climate change scenario in which CO_2 concentrations increase to approximately 575 ppm by the 2070s and then stabilise, resulting in a modelled global temperature rise of 1.8 C by 2100. RCP8.5 is the most extreme of the RCP scenarios, and may therefore represent the worst case scenario for reasonably anticipated climate change. In RCP8.5 atmospheric CO_2 concentrations increase to approximately 850 ppm by the 2070s, resulting in a modelled global mean temperature rise of 3.7 °C by 2100.

Finally, the recording density of mammals on GBIF was obtained as a proxy for spatial recording effort bias (Figure 1b).

Figure 1. (a) Occurrence records obtained for *Callosciurus finlaysonii* and used in the modelling, showing the native range and (b) a proxy for recording effort – the number of mammal records held by the Global Biodiversity Information Facility, displayed on a $\log_{10}$ scale.



Species distribution model

A presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.3-7 (Thuiller et al., 2009, 2016). Because invasive species' distributions are not at equilibrium and subject to dispersal constraints at a global scale (Elith et al., 2010), we took care to minimise the inclusion of locations suitable for the species but where it has not been able to disperse to. Therefore background samples (pseudo-absences) were sampled from two distinct regions:

- An accessible background includes places close to *C. finlaysonii* populations, in which the species is likely to have had sufficient time to disperse and sample the range of environments. *Callosciurus* species are generally considered to have relatively low dispersal abilities, and the most peripheral southern Italian record was approximately 40 km from other populations. Therefore we defined the accessible background as a 40 km buffer around non-native records, and a 100 km buffer around the minimum convex polygon bounding native records. Sampling was more restrictive from the invaded range to account for stronger dispersal constraint over a shorter residence time.
- An unsuitable background includes places with an expectation of environmental unsuitability, e.g. places too cold or dry. Absence from these regions should be irrespective of dispersal constraints, allowing inclusion of this background in the modelling. No specific ecophysiological information was available to define the unsuitable region, but based on expert opinion that cold and drought are likely to be limits on *C. finlaysonii* occurrence in Europe unsuitability was defined as:
    - Minimum temperature of the coldest month (Bio6) < -1 °C, OR
    - Mean temperature of the warmest quarter (Bio10) < 19 °C, OR
    - Annual precipitation (Bio12) < 600 mm.

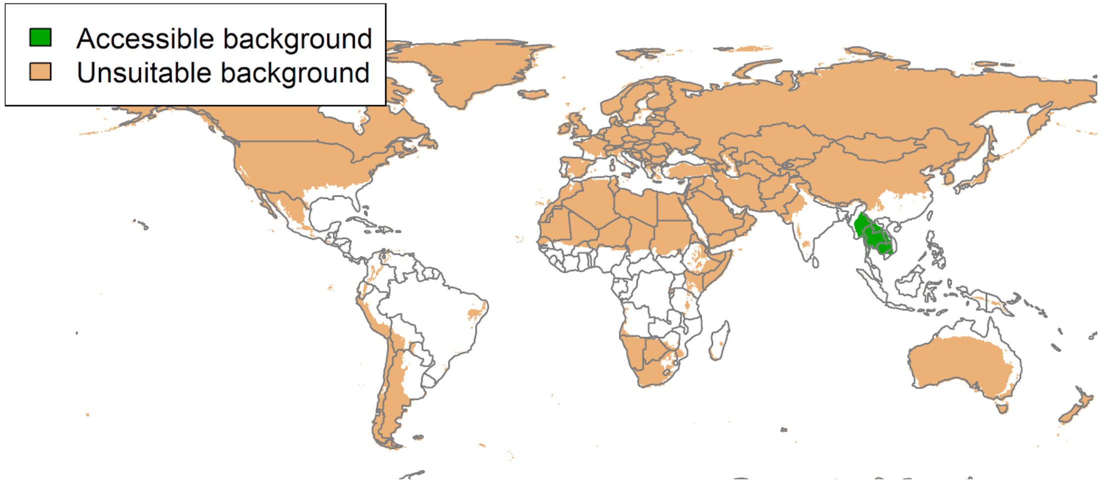
None of the 58 occurrences fell within the unsuitable background.

Ten random background samples were obtained:

- From the accessible background 58 samples were drawn, which is the same number as the occurrences. Sampling was performed with similar recording bias as the distribution data using the target group approach (Phillips, 2009). In this, sampling of background grid cells was weighted in proportion to mammal GBIF recording density (Figure 1b). Taking the same number of background samples as occurrences ensured the background sample had the same level of bias as the data.
- From the unsuitable background 3000 simple random samples were taken. Sampling was not adjusted for recording biases as we are confident of absence from these regions.

Model testing on other datasets has shown that this method is not overly sensitive to the choice of buffer radius for the accessible background or the number of unsuitable background samples.

Figure 2. The background regions from which 'pseudo-absences' were sampled for modelling. The accessible background is assumed to represent the range of environments the species has had chance to sample. The unsuitable background is assumed to be environmentally unsuitable for the species.



Each dataset (i.e. combination of the presences and the individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, seven statistical algorithms were fitted with the default BIOMOD2 settings (except where specified below) and rescaled using logistic regression:

- Generalised linear model (GLM)
- Generalised boosting model (GBM)
- Generalised additive model (GAM) with a maximum of four degrees of freedom per effect.
- Artificial neural network (ANN)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)
- Maxent (Phillips et al., 2008)

Since the background sample was much larger than the number of occurrences, prevalence fitting weights were applied to give equal overall importance to the occurrences and the background. Normalised variable importance was assessed and variable response functions were produced using BIOMOD2's default procedure. Model predictive performance was assessed by calculating the Area Under the Receiver-Operator Curve (AUC) for model predictions on the evaluation data, which were reserved from model fitting. AUC is the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected pseudo-absence.

An ensemble model was created by first rejecting poorly performing algorithms with relatively extreme low AUC values and then averaging the predictions of the remaining algorithms, weighted by their AUC. To identify poorly performing algorithms, AUC values were converted into modified z-scores based on their difference to the median and the median absolute deviation across all algorithms (Iglewicz & Hoaglin, 1993). Algorithms with $z < -2$ were rejected. In this way, ensemble projections were made for each dataset and then averaged to give an overall suitability.

Global model projections were made for the current climate and for the two climate change scenarios, avoiding model extrapolation beyond the ranges of the input variables. The optimal threshold for partitioning the ensemble predictions into suitable and unsuitable regions was determined using the 'minimum ROC distance' method. This finds the threshold where the Receiver-Operator Curve (ROC) is closest to its top left corner, i.e. the point where the false positive rate (one minus specificity) is zero and true positive rate (sensitivity) is one.

Limiting factor maps were produced following Elith et al. (2010). Projections were made separately with each individual variable fixed at a near-optimal value. These were chosen as the median values at the occurrence grid cells. Then, the most strongly limiting factors were identified as the one resulting in the highest increase in suitability in each grid cell. Partial response plots were also produced by predicting suitability across the range of each predictor, with other variables held at near-optimal values.

Results

The ensemble model suggested that at the global scale and resolution of the model suitability for *C. finlaysonii* was most strongly determined by precipitation, with strong effects of both temperature variables (Table 1). However, for the temperature predictors, there was substantial variation in the partial response plots between algorithms (Figure 3), highlighting the value in reducing this uncertainty through the use of ensemble model (Table 1).

Global projection of the ensemble model in current climatic conditions indicates that the native and known invaded records in Europe and Asia generally fell within regions predicted to have high suitability (Figure 4). In the native range, the model suggested a wider region of potentially suitable climate than is currently occupied. To some extent this is supported by the introduced populations in Singapore and the Philippines, but it does suggest that the current native range in continental Asia may be limited by factors other than climate, such as habitat availability of biotic interactions.

In Europe, the clusters of occurrences in northern and southern Italy were projected as being in climatically suitable locations (Figure 5). Beyond these, the model suggests climatically suitable regions occur widely around the eastern Mediterranean coast. The model also predicts suitable regions in the southern tip of Spain and in Portugal. Establishment in northern and eastern Europe was predicted to be prevented by low winter temperatures, while low summer temperatures were suggested as being more limiting in the Atlantic region (Figure 6). In unsuitable parts of the Mediterranean, low precipitation was identified as a strong potential limiting factor. Assuming thermal conditions were suitable in those regions, it remains possible that the species could establish where it has access to permanent water sources.

Predictions of the model for the 2070s, under the moderate RCP4.5 and extreme RCP8.5 climate change scenarios, suggest an eastwards shift in suitability in the Mediterranean (Figure 7-8). Suitable regions in Iberia appear to become too dry for the species, while warming benefits the species along the Adriatic coast. Climatically suitable conditions also appear in Western Europe, for example in the Atlantic coasts of Portugal, Spain and France and even as far north as Belgium and Netherlands. This is presumably driven by a combinations of warmer summers and milder winters.

In terms of Biogeographical Regions (Bundesamt fur Naturschutz (BfN), 2003), the Mediterranean and Black Sea regions are predicted most suitable for invasion in the current climate (Figure 9). Under the future climate scenarios, suitability in the Atlantic region increases markedly.

Table 1. Summary of the cross-validation predictive performance (AUC) and variable importances of the fitted model algorithms and the ensemble (AUC-weighted average of the best performing algorithms). Results are the average from models fitted to ten different background samples of the data.

Algorithm	AUC	In the ensemble	Variable importance		
			Minimum temperature of coldest month	**Mean temperature of warmest quarter**	**Annual precipitation**
GAM	0.9911	yes	31%	26%	43%
Maxent	0.9899	yes	40%	14%	46%
GLM	0.9869	yes	38%	21%	42%
ANN	0.9866	yes	35%	30%	35%
MARS	0.9860	yes	35%	24%	40%
RF	0.9849	yes	15%	25%	61%
GBM	0.9844	yes	34%	22%	43%
Ensemble	**0.9922**		**33%**	**23%**	**44%**

Figure 3. Partial response plots from the fitted models, ordered from most to least important. Thin coloured lines show responses from the algorithms in the ensemble, while the thick black line is their ensemble. In each plot, other model variables are held at their median value in the training data. Some of the divergence among algorithms is because of their different treatment of interactions among variables.

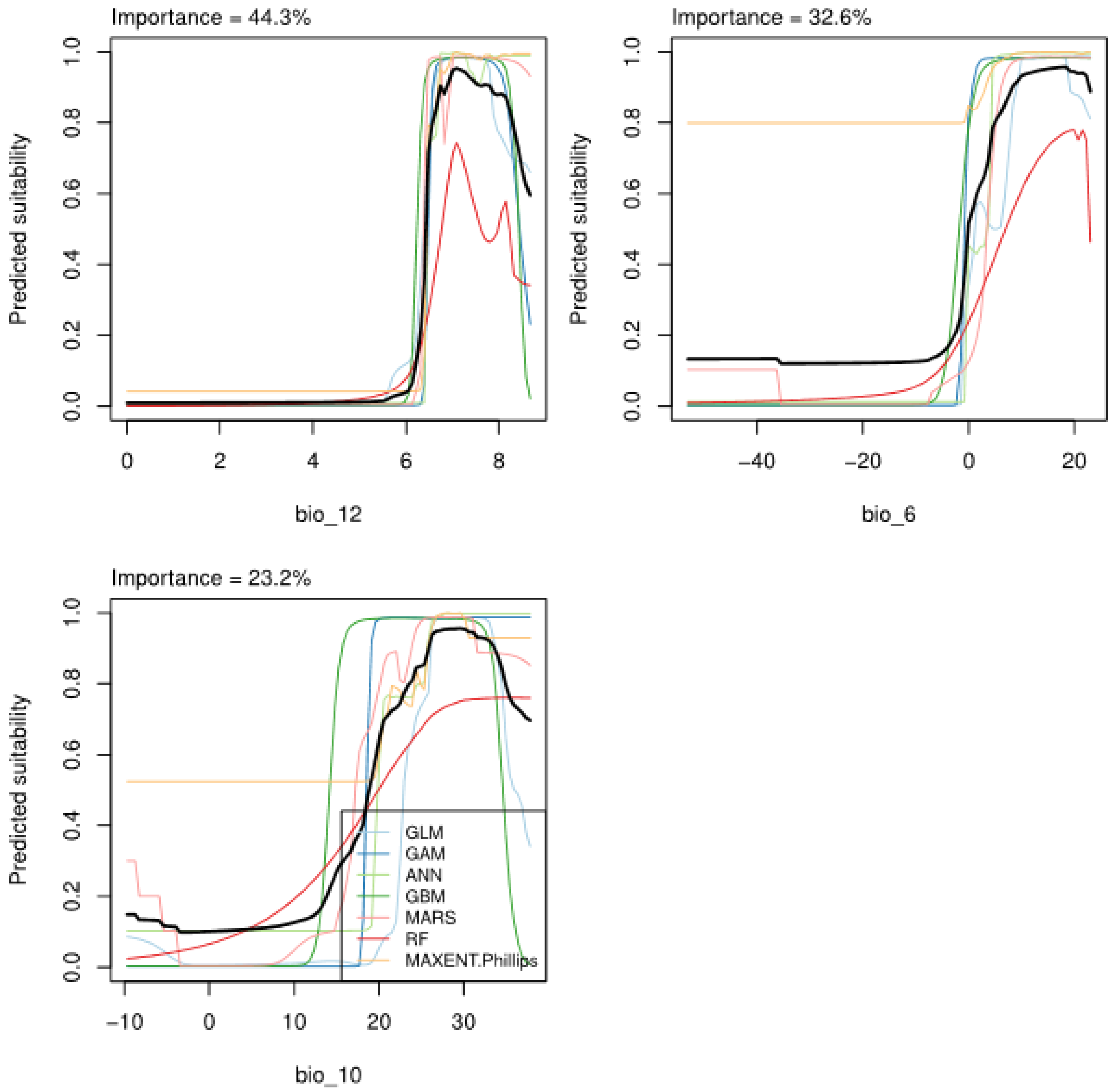

Importance = 44.3%
Predicted suitability
bio_12
Importance = 32.6%
Predicted suitability
bio_6
Importance = 23.2%
Predicted suitability
bio_10
GLM
GAM
ANN
GBM
MARS
RF
MAXENT.Phillips

Figure 4. (a) Projected global suitability for *Callosciurus finlaysonii* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Red shading indicates suitability. White areas have climatic conditions outside the range of the training data so were excluded from the projection. (b) Uncertainty in the suitability projections, expressed as the standard deviation of projections from different algorithms in the ensemble model.

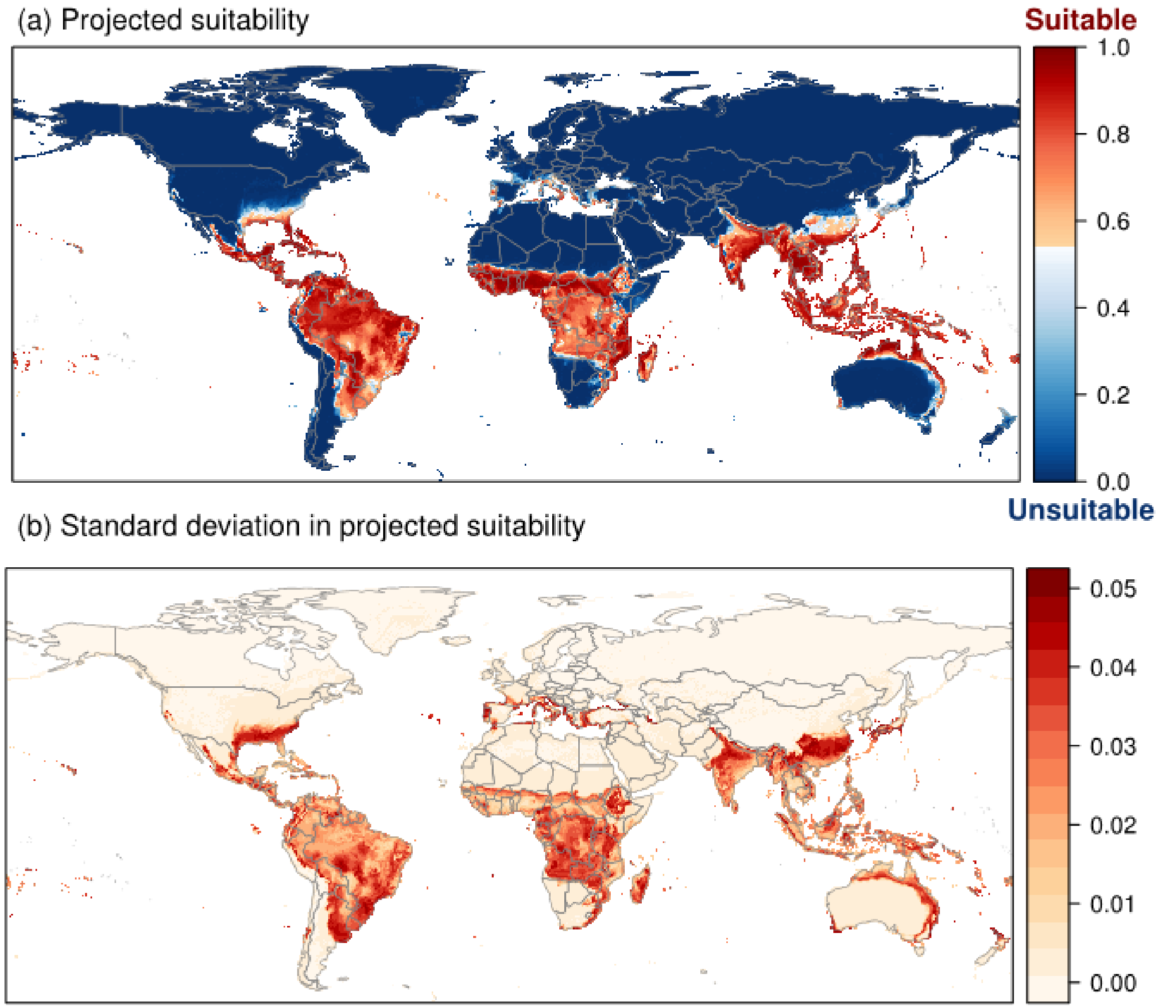


Figure 5. Projected current suitability for *Callosciurus finlaysonii* establishment in Europe and the Mediterranean region. The white areas have climatic conditions outside the range of the training data so were excluded from the projection.

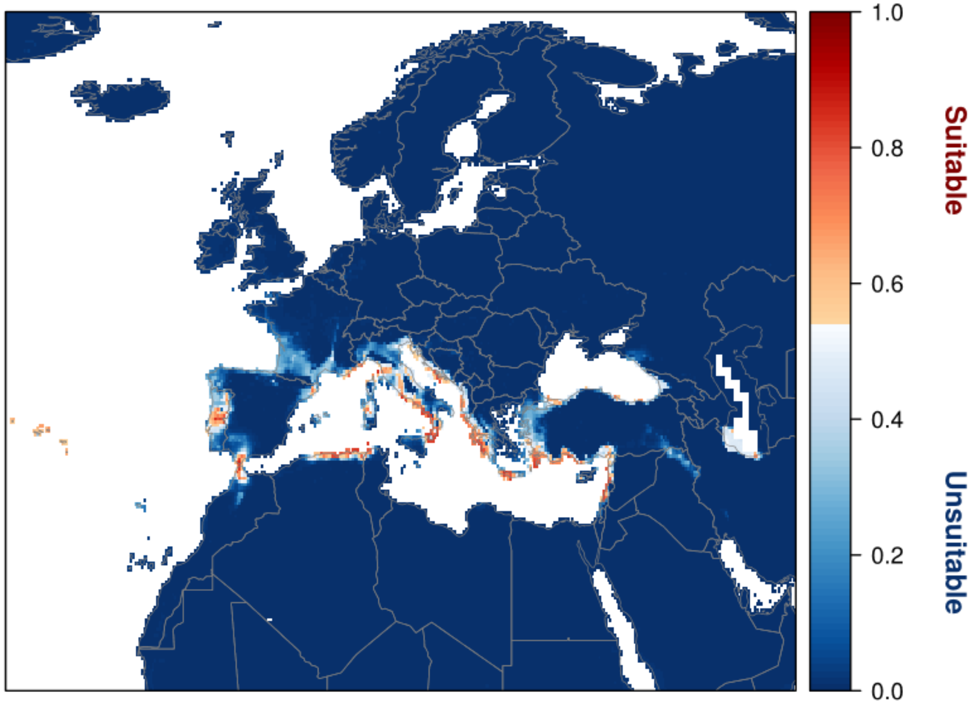


Figure 6. Limiting factor map for *Callosciurus finlaysonii* establishment in Europe and the Mediterranean region in the current climate. Shading shows the predictor variable most strongly limiting projected suitability.

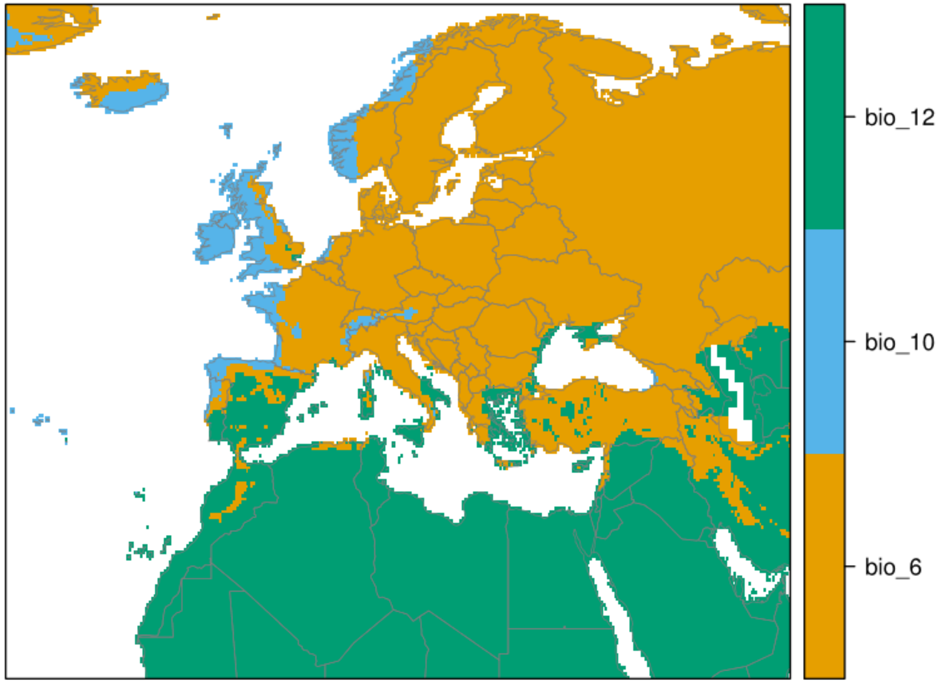

bio_12
bio_10
bio_6

Figure 7. Projected suitability for *Callosciurus finlaysonii* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP4.5, equivalent to Figure 5.

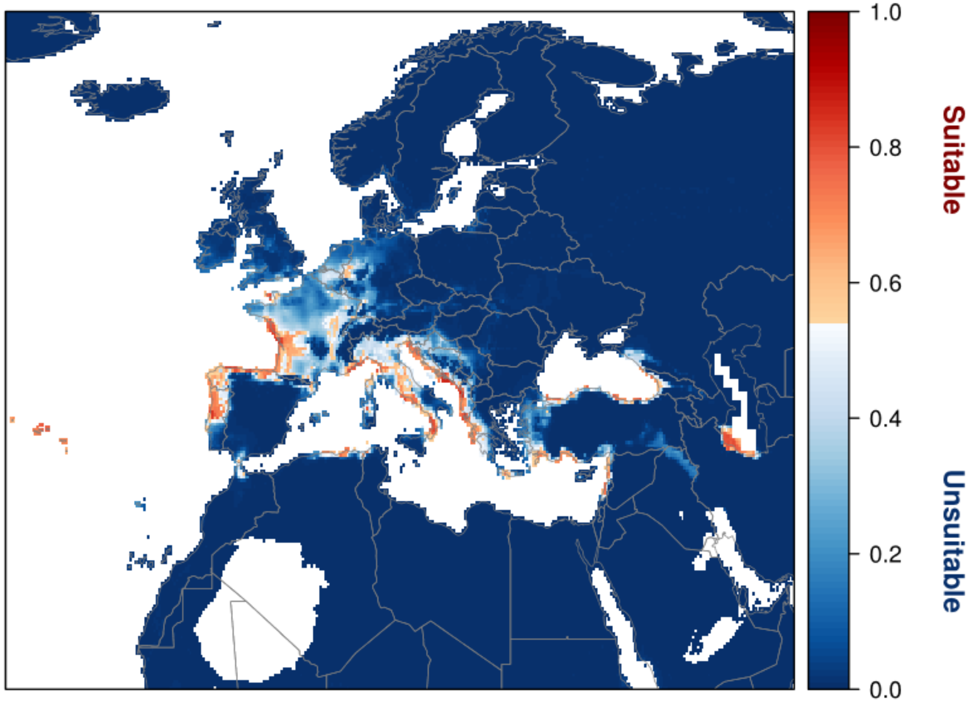


Figure 8. Projected suitability for *Callosciurus finlaysonii* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP8.5, equivalent to Figure 5.

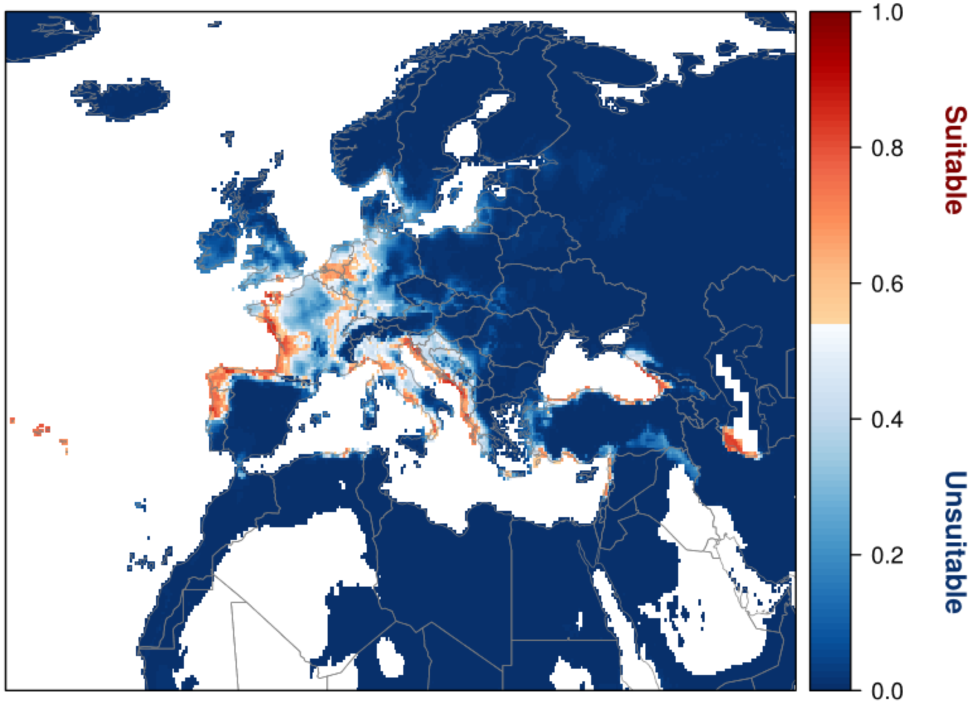
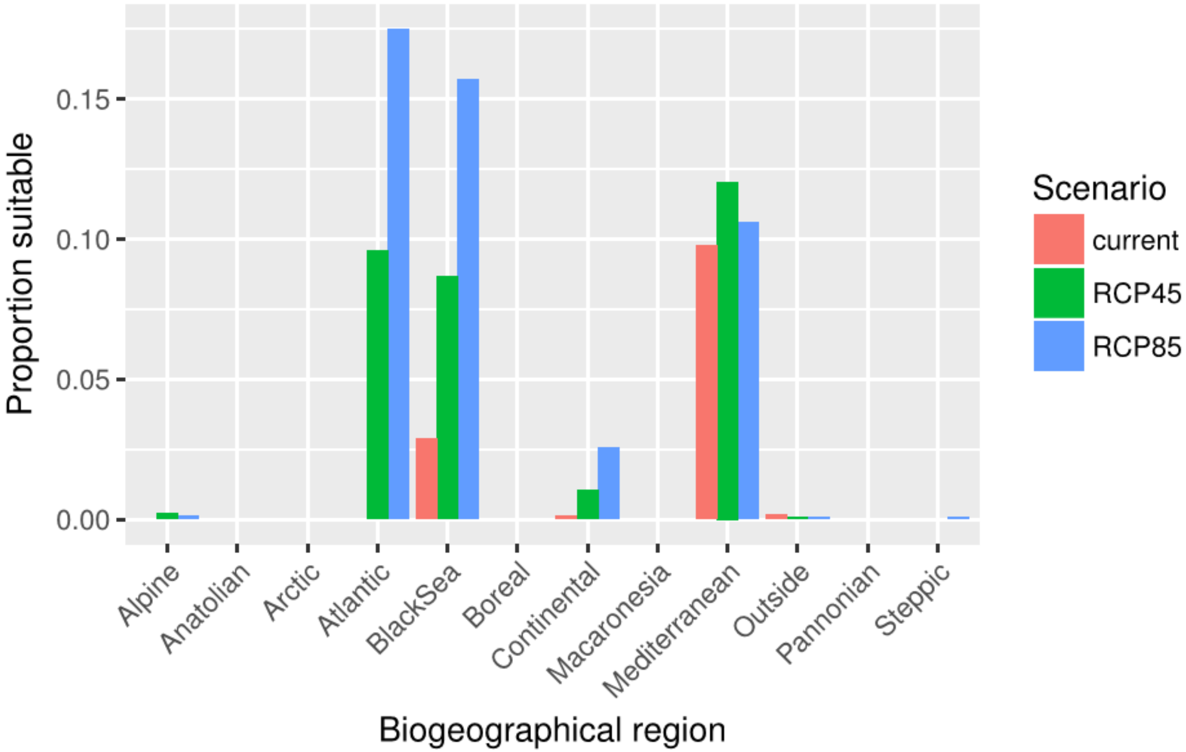
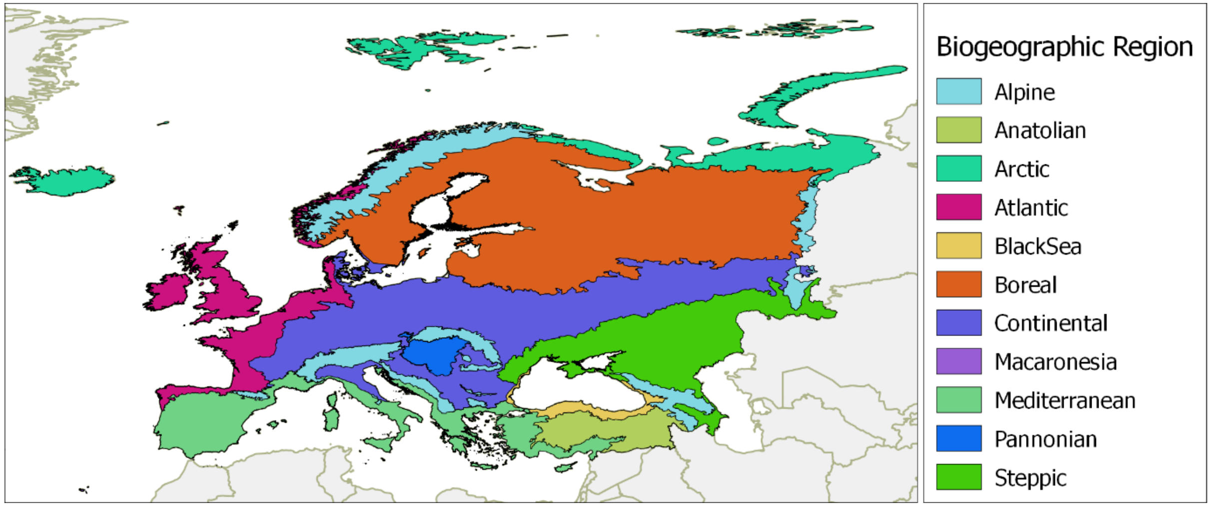


Figure 9. Variation in projected suitability among Biogeographical regions of Europe (Bundesamt fur Naturschutz (BfN), 2003). The bar plots show the proportion of grid cells in each region classified as suitable in the current climate and projected climate for the 2070s under emissions scenarios RCP4.5 and RCP8.5. The coverage of each region is shown in the map below.





Caveats to the modelling

Modelling the potential distributions of range-expanding species is always difficult and uncertain.

The modelling here is subject to a high degree of uncertainty for the following reasons:

- An unusually small number of distribution records was available for the modelling, possibly not capturing the full range of conditions in which the species can establish.
- There was no ecophysiological information available to contribute to definition of the unsuitable background region.
- *Callosciurus* species are known to be adaptable and may be able to expand their niche into cooler conditions than are currently observed.
- The role of precipitation as a limiting factor in Iberia and other parts of the Mediterranean may be overstated if the species has access to permanent water sources.

The model did not include other variables potentially affecting occurrence of the species, including habitat availability or biotic interactions. These were not included because of the very small number of distribution records.

To remove spatial recording biases, the selection of the background sample was weighted by the density of mammal records on the Global Biodiversity Information Facility (GBIF). While this is preferable to not accounting for recording bias at all, a number of factors mean this may not be the perfect null model for species recording, especially because additional data sources to GBIF were used.

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