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Successful eradication of an invasive alien Pallas's squirrel (*Callosciurus erythraeus* Pallas 1779) population in the Netherlands with support of the local community

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The Pallas's squirrel (*Callosciurus erythraeus*) is an invasive alien species in several countries in Europe, but also in Argentina and Japan. The species is a threat to indigenous squirrel species and difficult to eradicate. In 2008 a population of this species was discovered in the south of the Netherlands, close to the Belgian border. The range and number of Pallas's squirrels in the area was determined using sightings of local citizens, foresters and an extensive inventory with hair tubes and camera traps. The population was successfully eradicated during an eradication campaign with several stages from 2011 till 2015. The population appeared to be larger than expected. In total, 249 individuals were trapped in an area as large as 50km^2. Trapped squirrels were not killed, but sterilized and rehomed in animal parks across Europe. The eradication campaign was successful due to the cooperation and support of the general public, who were informed by flyers, lectures and several appeals in local media and on social media platforms. Both helped in getting support of the general public, but sterilization and rehoming must be properly supervised. The total costs of eradication summed up to at least €330,000. No Pallas's squirrels were reported after October 2015, however sightings of 'dark colored' squirrels from the area are still reported by the general public and verified by an expert of the Dutch Mammal Society until today.

KEYWORDS

invasive alien species, squirrel, general public, communication, wildlife management

Introduction

The Pallas's squirrel *Callosciurus erythraeus* (Pallas, 1779) is native to South-East Asia. As a result of animal trade it became an invasive alien species in Europe (Dozières et al., 2015; Bertolino et al., 2016), Argentina (Guichón and Doncaster, 2008) and Japan (Tamura et al., 2013). It poses a threat for populations of indigenous squirrel species by competition, resulting in, for example, a negative effect on body condition (Mazzamuto et al., 2017). Since August 2016 the Pallas's squirrel is included in the list of Invasive Alien Species of European Union concern, the Union list (European Union, 2017).

In 2008 a population of Pallas's squirrels was discovered near the city of Weert (WGS84: 51.245; 5.714) in the south of the Netherlands, close to the border with Belgium (Dijkstra et al., 2009, 2011) over an area as large as 50 km^2. After this discovery, it became clear that around 10 squirrels had escaped from the premises of a local trader in exotic species around 1998. Their escape had never been reported to the authorities.

The range and number of Pallas's squirrels in the area around Weert was determined using sightings of local citizens and foresters, and an extensive survey using hair tubes and camera traps. Based on these data the number of individuals was estimated to be between 50 and 110 (Dijkstra et al., 2009, 2011).

The Pallas's squirrels in Weert had a red belly and a white tip at the end of the tail. A DNA analysis to identify the exact subspecies or clade was not performed and there's an ongoing taxonomic discussion how to interpret the 'Pallas-clade' (Balakirev and Rozhnov, 2019).

To stop further spread and growth of this reproducing population, the responsible national and provincial authorities decided to attempt eradicating all Pallas's squirrels in the area. Eradication was initiated to prevent negative impacts on native European red squirrels (*Sciurus vulgaris* L. 1758), but also to avoid further damages to trees and houses in the area.

Reports of successful eradications projects in mainland areas are still scarce (Robertson et al., 2017). This may lead to pessimism about the feasibility of eradication invasive alien species, which makes it important to describe and report cases of successful eradications (Adriaens et al., 2015). This paper describes what was done to successfully remove the Weert population.

Materials and methods

Informing the public

The eradication project went through several stages with evaluations in between. The first stage was to inform the citizens of Weert and nearby villages, including landowners, hunters, farmers, nature conservationist and other stakeholders to explain the objectives of the project, to gain support and ask for help in mapping the presence of Pallas's squirrels. This was the first time that the general public was informed about the planned eradication campaign. We also explained the general public their support would help in the conservation of the appealing native European red squirrel. From the start of the eradication campaign the general public was regularly informed and asked to report dark colored squirrels. During the project, information on the species was made available on the website of the Dutch Mammal Society, including an online form to report observations and a telephone number for enquiries and for reporting sightings. Additionally, a flyer (Supplementary Figure S2) was spread door-to-door and several public presentations were given in a local nature center to report on the progress of the eradication project and to ask for new observations.

Setting up the project team

An advisory board was compiled with the Dutch Mammal society, national, provincial and municipal authorities, landowners and the nature conservation organization Natuurmonumenten to oversee the project. The team was led by a project leader at the Dutch Mammal society (MLH). The trapper team consisted of two till three experienced mammologists. Staff of the Nature Rehabilitation Center (NHC) in Opglabbeek (Belgium) helped with the surgical sterilization and rehoming of trapped individuals. The Dutch Mammal Society had permits to trap wild species of mammals and birds under the Flora and Fauna Act, numbers FF/75A/2008/046 and FF/75A/2012/037a.

Trapping

In the second phase, live trapping of Pallas's squirrels was initiated. It was decided to adopt a strategy of live trapping and not to resort to lethal methods such as shooting, kill trapping or toxic baiting (*cf.* Smith et al., 2022), as the support of the general public was crucial. Besides, shooting exotic species is forbidden in the Netherlands, unless specific permission is granted, which was not the case. Also, the use of kill traps and toxic bait for squirrels is not legal in the Netherlands.

A large part of the squirrel population persisted in and around gardens. Removing these squirrels required active community engagement for reporting Pallas's squirrel occurrences and required gaining permission for trapping in private gardens, which was easier when trapped squirrels would not be killed.

The trapping campaign was initiated in the winter of 2011–2012, with over 300 live traps deployed in the area. In the next winter of 2012–2013, the trapping scheme was repeated (Dijkstra and Bekker, 2012; Dijkstra, 2013a,b). Trapping efforts were concentrated in winter and spring (November–April, Figure 1), because of a reduced availability of food, making baited traps more attractive. Also, from an animal welfare perspective, this prevented the trapping of lactating females. We continued trapping in summer, but with a lower intensity and only after reliable reports of squirrels by citizens. Pallas's squirrels were trapped with different live-traps including the Tomahawk 202 (Tomahawk Live trap, Hazelhurst, WI, United States) and handmade mesh-wire traps (dimensions 17x16x49 cm) which were previously used in the Dadizele campaign in Belgium (Adriaens et al., 2015). Trapping of Pallas's squirrels inside the city of Weert and surrounding villages was mainly performed in gardens, where squirrels were regular visitors of bird feeding platforms. In each garden, between two and five traps were installed and baited with walnuts. Residents were asked to check the traps at least twice a day around noon and after dusk and to inform trappers when a Pallas's squirrel was trapped or when it was needed to rebait the traps. In the rare case that a lactating female was trapped, the animal was released after applying a small VHF collar (PIP3 button celled tag + collar, Biotrack, Dorset, United Kingdom) around the neck. These females were tracked back to their nest. This was followed by putting a live trap in front of the tree cavity, which was secured with bands, to re-trap the collared female. After re-trapping the female, the hole was widened by drilling and the juveniles were grabbed by hand.

All live traps were rebaited after each capture and installed again. During the first months, traps were mainly placed in gardens, but from December 2011 onwards more traps were set in the nearby countryside in small pieces of woodland which were connected through tree rows. Trapping continued as long as new individuals were seen or trapped. When no further squirrels were trapped and no observations of Pallas's squirrels were done for a period of 2 weeks, traps were relocated to new locations. Suitable trapping locations were selected based on the presence of fresh signs, indicated through the absence of algae, of bark stripping or wounds on trees (Figure 2). The trappers searched the area to locate active bark stripping locations and placed traps when such

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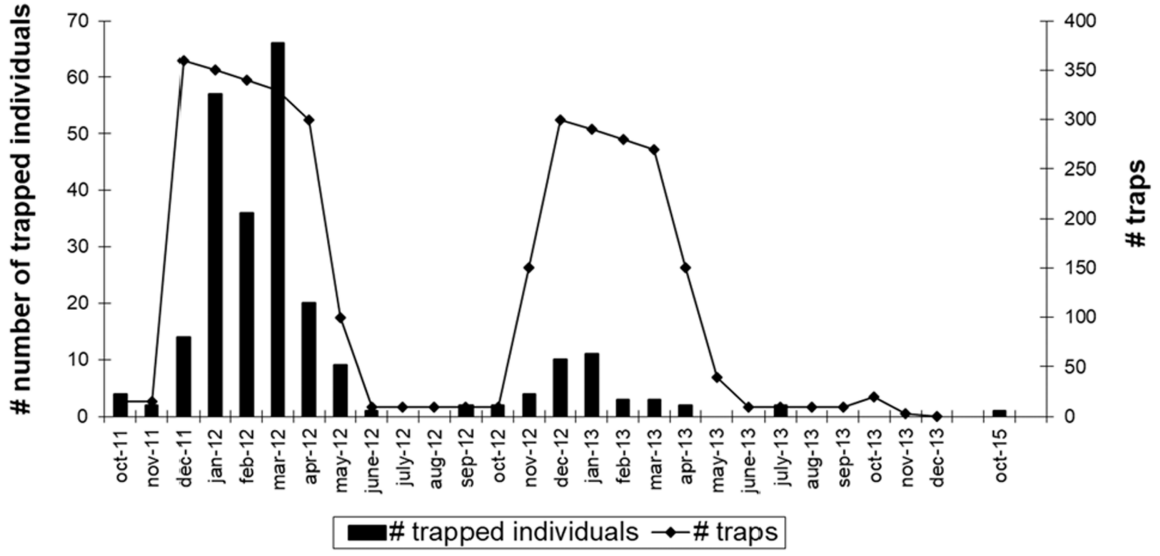

FIGURE 1
Number of Pallas's squirrels trapped and the number of traps deployed per month in the field. Active trapping campaigns were run in winter–spring of 2011–2012 and 2012–2013. Afterwards, trapping was only on request till the end of 2013.

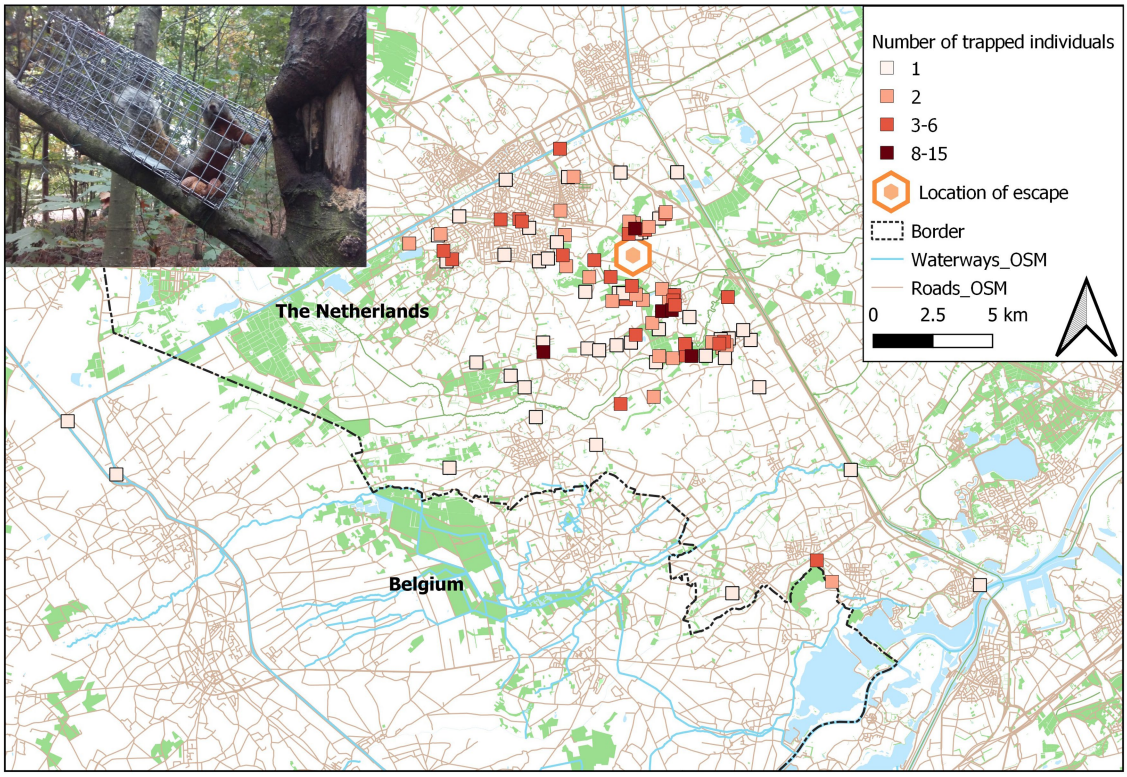

FIGURE 2
Overview of Weert and the number of trapped Pallas's squirrels in the period 2011–2013. Inset, the last Pallas's squirrel that made number 249, near an old wound of bark stripping. The black line is the border with Belgium (Southwestern part of the map).

locations were found (Dijkstra et al., 2014). Also, here, traps were baited with walnuts and checked twice a day, around noon and after dusk. Each trap was active during four or five days a week, and the other days were used for pre-baiting by blocking the trap entrance and offering *ca.* 10 walnuts per trap. Another method, especially used outside Weert in areas with a lack of garden owners reporting squirrels, was to establish feeding spots to attract squirrels. When Pallas's squirrels were using these spots, the same procedure was followed as in gardens.

Dispatch, sterilization and rehoming

Trapped Pallas's squirrels were transported on a daily basis to the Nature Rehabilitation Center, where all individuals were surgically sterilized and thereafter rehomed in zoos or animal parks across Europe. Because sterilization was done group wise, it was not possible to collect detailed information of each squirrel, like age, sex or body condition, to a specific location or trapping event.

Post-eradication survey phase

After two seasons of trapping an extensive survey of most of the area, including forests in Belgium, was performed by three field workers who were trained to recognize specific signs of Pallas's squirrel presence: large leaf nests and/or fresh signs of bark stripping.

Results

The official first trapping campaign started in October 2011 and lasted until the end of June 2012. During this period, 209 individuals were trapped (Figure 1; Supplementary Table S1), with an even sex ratio of 1:1. The number of trapped individuals steeply increased in the first months, dropped during a period with severe cold in February 2012, but increased again afterwards (Figure 1). An increasing number of sightings were reported as the trapping campaign got more media attention, including confirmed sightings of Pallas's squirrels up to 11 kilometers from the location of their escape. After the first trapping period, it became clear that individuals were mainly trapped within an area limited by a canal in the east and northwest (the Zuid-Willemsvaart). The southern limit of the range coincided with the Belgian border, which did however not form a physical barrier (Figure 2). A specific hotspot with higher densities of Pallas's squirrels was nature reserve De Krang (Weert). This area consists of forest with deciduous and pine trees, alternated with meadows and arable land. The core of the reserve is very wet, with a small stream crossing the area from the south to the north, surrounded by alluvial forest with a dominance of black alder *Alnus glutinosa*. After the second trapping season during the winter of 2012–2013, when another 37 Pallas's squirrels were trapped, no individuals were seen or reported anymore in the project area. A search for Pallas's squirrels in spring 2013 in Belgian forests just across the border, revealed the presence of two more Pallas's squirrels. These individuals were trapped in July 2013. In the post-eradication phase (2013–2015), no nests nor fresh signs of bark stripping were detected and no Pallas's squirrels were seen or reported in the area anymore, until finally a single individual was trapped in October 2015, almost 2.5 years after the start of the trapping campaign. This individual was reported by an inhabitant of the countryside who was informed and motivated to report the sighting, because of the repeated calls in local media and the catch of individuals in her garden in the previous trapping periods. In total, 249 Pallas's squirrels were trapped. The number of individuals that were illegally shot by hunters remained unclear, but we expect it to be not more than a handful.

All non-target species, including native red squirrels, great tits *Parus major* L. 1758, and great spotted woodpeckers *Dendrocopus major* L. 1758 who were entering the traps repeatedly for an easy meal, were directly released at the location by the residents or the trapping team. We were not able to accurately record the number of trapped non-target species, because traps were checked by local residents, who did not consistently report bycatch and mostly only informed the trapping team when a Pallas's squirrel was trapped.

Around 20 live traps were stolen, disabled and/or demolished, despite the traps being hung in trees several meters above the ground. Cables and locks prevented further theft after such incidents. It is unclear what the reasons for these acts were. In the case inhabitants refused to put traps in their gardens, we searched for nearby locations to trap resident squirrels, which in all cases worked out well. The total costs of the project summed up to *ca.* €330,000 over the period 2011–2015 (Table 1). The highest costs were incurred for the actual trapping of squirrels (€107,000), but also post-eradication surveys were expensive because of the large area which had to be checked. Preparation and coordination, including communication, was nearly €70,000. The costs of surgical sterilization and rehoming was only 4.5% of the total budget, because the Nature Rehabilitation Center offered to organize this for €60 per squirrel. This was a very favorable offer which greatly reduced the cost of rehoming.

Discussion

In this article we describe a successful eradication project of an established population of Pallas's squirrel in the Netherlands. The species is nowadays listed as an invasive alien species of European Union concern (European Union, 2017), with the obligation to eradicate new populations. The population was present in an area of *ca.* 50 km^2 in and around the city of Weert and other nearby villages, also some individuals crossed the border with Belgium. Successful eradication of a population of alien squirrels is rare but not unique. A population of Pallas's squirrel was successfully eradicated from a suburban park in Dadizele, Belgium (Adriaens et al., 2015). Although the response to the outbreak in Dadizele was relatively rapid and the invasion extent limited to a core area of about 2.7 km^2 (Robertson et al., 2017), it still took 5 years to eradicate it, including 1.5 years of post-eradication surveys and an investment of €200,000. Part of the success of this action in Dadizele was

TABLE 1 Costs of eradication of Pallas's squirrels (*Callosciurus erythraeus*) in the area around Weert, the Netherlands in the period 2008–2015.

Coordination	
Meetings	€1,354
Preparation and coordination	€56,526
Communication to the general public	€12,350
Data analysis and reports	€22,288
Trapping	
Live traps	€4,952
Bait	€500
Wildlife camera-traps	€6,000
Transport trappers	€11,855
Trapping hours	€107,216
Other materials	€2,061
Rehoming of trapped squirrels	
Rehoming and sterilization (offer of €60 per individual)	€15,000
Post-eradication surveys	
Searching for fresh signs of bark stripping and/or large leaf nests	€91,274
Total costs	€331,376

attributed to the insular context of the case, with squirrels present in small, isolated park fragments surrounded by arable land inhospitable to squirrels. In contrary, the eradication from the Netherlands described in this paper was conducted over a much larger area and the actions were complicated by a more forested context with lots of private gardens. One important difference compared to Dadizele was the high number of squirrels trapped in our study during the first trapping campaign (October 2011–May 2012), which probably prevented much of the reproduction in the following summer. As a result, the population could be depleted within two trapping campaigns only. We believe the assumption that signs of bark stripping indicated good trapping locations, contributed to the efficient capture of squirrels.

The eradication project described in this article shows that it is possible to achieve full eradication of Pallas's squirrel within a limited timeframe, even if the population is widespread. However, eradication still takes some years, extensive post-eradication monitoring and a continued investment in awareness raising. Also, the late capture of a remaining individual illustrates that funding and willingness of an expert to rapidly respond to sightings of Pallas's squirrels, several years after the campaign, is important to consolidate success. Looking back, we have to conclude that both the distribution area as well as the number of individuals were largely underestimated, which was also the case in Dadizele (Adriaens et al., 2015). This underestimation of the size of the population shows that it is difficult to accurately estimate the number of Pallas's squirrels in an area, especially when numbers or densities are low (Tamura et al., 2013). Despite this, the eradication was a success, therefore the lack of accurate assessment of population density did not represent too much of a barrier to removing all animals and probably the rough initial assessment of invasion extent was fairly accurate. The first trapping campaign already removed high numbers of squirrels, which probably prevented a quick increase in population numbers during the next reproductive season.

The total area where Pallas's squirrels were trapped covered *ca.* 50 km^2, with sightings of single individuals at distances up to 11 km from the location of the pet trader where the species had escaped. Two specific areas with higher numbers of squirrels were identified, one being the urban area of Weert, where squirrels lived in gardens and small parks. In this area squirrels found food on bird feeding platforms and some residents were actively feeding these 'nice and remarkable' squirrels. The other hotspot was nature reserve 'De Krang'. It is not clear why this area was so attractive for the species, but it is known that these squirrels are highly adaptive and capable of surviving in various habitats (Bertolino and Lurz, 2013). Looking at the map of the area (Figure 2), it appears that the canals on the eastern and northwestern side of Weert acted as barriers for Pallas's squirrel dispersal to other suitable areas. Almost all squirrels were trapped south of these canals and very few sightings or signs of squirrel presence were reported on the opposite side. In France the motorway A8 (E80) initially acted as a barrier (Dozières et al., 2015) and slowed down the expansion of that Pallas's squirrel population, at least for a while. This observed sensitivity to anthropogenic barriers, such as canals and motorways, is therefore important when planning eradication campaigns of Pallas's squirrels. All trapped Pallas's squirrels were brought to the Nature Rehabilitation Center and surgically sterilized by a veterinarian. The Nature Rehabilitation Center reported that a significant number of squirrels died because of stress. The exact number of rehomed individuals is not known and only from 67 individuals this information was found in their archives. These individuals were rehomed to zoos and animal parks in the Netherlands ($n = 36$), Hungary ($n = 6$), Germany ($n = 10$) and the United Kingdom ($n = 15$). Within the local context which required convincing garden owners to allow actions on their premises (*cf.* Bertolino et al., 2021) and with the general public sensitivity in the Netherlands for animal welfare issues (Vane and Runhaar, 2016), we believe this strategy of live trapping has helped to ensure support of the public. However, from the animal welfare point of view it is questionable if rehoming, causing stress and a high mortality, is an acceptable method.

In some cases, where private people were not supportive of the measures and did not allow the placing of traps, alternative locations were sought nearby. We acknowledge that sterilization and rehoming was only possible due to the relatively small number of individuals trapped and the active cooperation of the Nature Rehabilitation Center. In Dadizele the same strategy of live trapping, sterilization and rehoming was followed in the first phase, but soon, when the number of live trapped animals increased, trapped individuals were killed using carbon dioxide (Adriaens et al., 2015).

Sterilization and rehoming to animal parks is also not without risk when this procedure is not strictly controlled and monitored. Dijkstra and La Haye (2017) described a case from the Netherlands where a group of sterilized Pallas's squirrels from the Dadizele eradication were rehomed to a small animal park in the Netherlands, but escaped into the wild again soon after. One female was caught in the wild 11 years later, killed and examined by a veterinarian. The animal had not been sterilized and, if not for the lack of males, could have formed a new population (Dijkstra and La Haye 2017).

Also, as a consequence of the group-wise sterilization, we were unable to gather more data on age and sex of the trapped individuals which could have been informative to the campaign by giving an idea on the demography and reproductive status of the population in Weert. Despite this, the removal eventually succeeded.

During the trapping sessions unconfirmed reports came in suggesting that hunters had shot some Pallas's squirrels, although it is only legal to shoot exotic species in the Netherlands with specific permission which was absent. Hunting in gardens or in the public area is also strictly forbidden and dangerous. The effectiveness of hunting highly depends on the effort spent but also the detectability of the species. On many of the locations where Pallas's squirrels were trapped in cages, the animals were never observed directly by local residents or by professional field workers. They were often only detected because of signs of bark stripping. Therefore, we question the contribution of hunting as an effective method for eradication and we are convinced that without active searching for squirrel presence and live trapping it would have been impossible to remove the entire population.

Shortly after the population had been discovered near Weert, a public communication campaign was initiated. All inhabitants in the area received a flyer explaining the negative impact of Pallas's squirrel on native red squirrels and showing observed damage to houses and trees (see Supplementary Figure S2). Informing citizens in the area was essential, as large numbers of these squirrels were living in gardens and backyards. Some people were also actively feeding the squirrels and were not aware of the negative effects of their presence. Showing pictures of damages to trees, houses (drain pipes, roofs) and garden furniture caused by Pallas's squirrels, helped to gain support for the eradication campaign.

Despite these efforts some live traps were stolen, disabled or demolished. However, generally, trapping went well without major problems, and communication contributed to this. In case of inhabitants refusing to put traps in their garden, other nearby locations were selected to trap resident squirrels.

Getting permission to enter and look for Pallas's squirrels in small pieces of woodland in the countryside was more challenging. Private landowners were not always cooperative to give permission to enter

their properties, as was also noted in Italian gray squirrel campaigns (Bertolino et al., 2021). The last trapped squirrel was found just outside such a private estate, highlighting the importance of gaining access to all or at least as much private property as possible. As this represents a prerequisite for success, for future eradication campaigns, legally enforced access to land by professional personnel for eradication purposes would be beneficial. The species' legal status as an invasive alien species of Union Concern should help instate this and several European Member States have already foreseen such provisions. For instance, in Flanders (Belgium), legal access can be enforced for Union List species on the condition of a management regulation.

When conducting communication, it is important to continuously repeat the same messages for a longer period of time. The experience in Weert showed that often only parts of the messages were remembered, especially the information on how to distinguish a Pallas's squirrel from a dark colored European red squirrel. This led to misidentifications of reported squirrels and therefore loss of time during the campaign. It is clear that a continued communication and clear leaflets on identification and reporting were an essential part of this eradication project. This can be achieved by carefully considering these aspects when drafting a communication plan. A communication strategy should be commonplace in eradications of alien squirrels (Vane and Runhaar, 2016). The general public highly appreciates squirrels, no matter the species. It is crucial that the general public knows alien squirrel species can have detrimental effects on native squirrels and may also cause other problems, if not apparent now, then in the future. Pallas's squirrels exhibit clear socio-economic impacts, damage to trees and nurseries and cable gnawing, which has been suggested to increase public support to undertake action (Pers. comm. L. Wauters). The same advice is relevant regarding the gray squirrel *Sciurus carolinensis* Gmelin, 1788 (Bertolino et al., 2016). An eradication program may seem expensive in the short term, but in the long term eradication is in most cases a cost effective and a rational action to undertake (Genovesi et al., 2010; Adriaens et al., 2015). The costs of eradicating Pallas's squirrels in the area summed up to more than €330,000 (Table 1). Most of the budget was spent on trapping and the post-eradication surveys. Rehoming and sterilization luckily represented only a minor cost in this project, but it is questionable if that will be the case in similar projects elsewhere. If the population had been larger, euthanasia could have been an alternative method of dispatch, although this would represent a risk of losing support of the general public as with other cases of invasive alien species removal in the Netherlands (e.g., Vane and Runhaar, 2016).

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the animal study because Vertebrate control in the Netherlands is not required by law to be reviewed by an ethics committee.

Author contributions

MH coordinator of the project as of 2014. RJ trapped squirrels, analyzed the data and revised several versions of the manuscript. TA gave valuable advice during the project and revised several drafts of the article. FH commented on an earlier version of the article. PV advised during the whole project and commented an earlier version of the article. WL advised during the whole project and revised an earlier version of the article. VD involved in the project during 2011–2014, revised several versions of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1081138/full#supplementary-material

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