

*Successful eradication of a suburban
Pallas's squirrel Callosciurus erythraeus
(Pallas 1779) (Rodentia, Sciuridae)
population in Flanders (northern Belgium)*

**T. Adriaens, K. Baert, P. Breyne,
J. Casaer, S. Devisscher, T. Onkelinx,
S. Pieters & J. Stuyck**

Biological Invasions

ISSN 1387-3547

Volume 17

Number 9

Biol Invasions (2015) 17:2517-2526

DOI 10.1007/s10530-015-0898-z



Your article is protected by copyright and all rights are held exclusively by Springer International Publishing Switzerland. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at link.springer.com".

Successful eradication of a suburban Pallas's squirrel *Callosciurus erythraeus* (Pallas 1779) (Rodentia, Sciuridae) population in Flanders (northern Belgium)

T. Adriaens  · K. Baert · P. Breyne · J. Casaer · S. Devisscher · T. Onkelinx · S. Pieters · J. Stuyck

Received: 4 December 2014 / Accepted: 7 May 2015 / Published online: 20 May 2015
© Springer International Publishing Switzerland 2015

Abstract Despite a growing catalogue of eradication projects, documented successful vertebrate eradications on the mainland remain scarce. Reporting on successful campaigns is crucial to counter pessimism on ambitious programmes to tackle invasive species and to allow conservation practitioners, wildlife managers and scientist to learn from previous experience. Moreover, there is a need for basic information on the effectiveness of control methods and management strategies that can be used. In this note we report on a successful low-tech eradication campaign of a local population of Pallas's squirrel *Callosciurus erythraeus*, a species of tree squirrel with documented ecological and socio-economic impacts in its invasive range. The population was eradicated from a suburban park of about 15 ha using baited mesh wire life traps, in five consecutive capture campaigns between October 2005 and January 2011. Using maximum likelihood estimation from catch-effort data we calculated initial densities in the park at 3 squirrels ha⁻¹. Although control started quickly and

the extent of the invasion was limited, the campaign took over 5 years and required an estimated investment of over €200,000 including 1.5 years of post-eradication surveying. We provide basic data on the methods used to eradicate this invasive rodent. Critical success factors and possible improvements with respect to the specific context of this case are discussed. Adding this species to the list of species of EU concern currently under development could provide incentive to minimise impact of this tree squirrel at the continental scale.

Keywords Invasive alien species · Non-native species · Eradication · Rodents · Wildlife management

According to the Convention on Biological Diversity (CBD 1992), the most effective way to manage the impacts caused by invasive alien species (IAS) is the prevention of new, unwanted introductions. Once prevention has failed, eradication comes as the second best option (Genovesi et al. 2010). This involves the complete and permanent removal of all wild populations of an IAS from a defined area, by means of a time-limited campaign (Bomford and O'Brien 1995). Eradication often suffers from lack of enthusiasm amongst conservationists, authorities and the general public because it represents an activity that many people find distasteful (Bremner and Park 2007; Temple 1990). Due to a few well-known failed eradication campaigns

Electronic supplementary material The online version of this article (doi:10.1007/s10530-015-0898-z) contains supplementary material, which is available to authorized users.

T. Adriaens (✉) · K. Baert · P. Breyne · J. Casaer · S. Devisscher · T. Onkelinx · S. Pieters · J. Stuyck

Research Institute for Nature and Forest (INBO),
Kliniekstraat 25, 1070 Brussels, Belgium
e-mail: tim.adriaens@inbo.be

with notable non-target effects, unsuccessful eradication or control actions are generally better known than successful ones (Simberloff 2009). Also, unsuccessful eradications are often widely reported in the literature and the media, whilst successful campaigns may be noted in the grey literature only. This is fuelling the often heard lament that resistance to the ever growing army of IAS is futile and is also hindering the ability of scientists to learn from previous efforts. Genovesi (2007) also noted that the results of prompt eradication projects (removals carried out in the early stages of invasions) are often not published at all. To balance the knowledge on unsuccessful and successful eradication actions and to allow capacity building, invasion ecologists need to report more on management successes. With the set-up of an online database on island eradications by IUCN (Keitt et al. 2011), information on past and running eradication campaigns became more accessible. There is also an increasing story of success for invasive alien animal eradications in Europe, predominantly involving non-native fish (Britton and Brazier 2006; Britton et al. 2010; Caffrey et al. 2008) and rodents or carnivores on islands (Genovesi 2005; Howald et al. 2007; Martins et al. 2006; Moore et al. 2003). Although the frequency of eradications that were reported as successful increased in the last decade (Genovesi 2007; Genovesi and Carnevali 2011), most information still originates from islands (Genovesi 2005). Although there are some exceptions, such as the eradication of coypu *Myocaster coypus* in England (Gosling and Baker 1989), Canadian beaver *Castor canadensis* in France (Rouland 1985) and the ongoing eradication of ruddy duck *Oxyura jamaicensis* in Europe (Robertson et al. 2015), there is still a paucity of precise information on eradication and management actions, especially on the European continent and on vertebrates. Genovesi and Carnevali (2011) also noted that it was generally difficult to gather data on the costs of eradication campaigns, and several authors point to the importance of providing economic data on invasive mammal eradication campaigns, and conservation efforts in general, as this is a critical element for defining future policies (Donlan and Wilcox 2007; Naidoo et al. 2006; Williams et al. 2010). Furthermore, publishing data from case studies is essential to quantify eradication probabilities and to underpin evidence-based decision making in IAS management (Drolet et al. 2014, 2015). Finally, there is clearly a need among conservation managers for basic information on the

type and effectiveness of control methods and the management strategies to be used (Esler et al. 2010). In this note we report on a successful eradication of a population of the invasive Pallas's squirrel *Callosciurus erythraeus* (PALLAS 1779) from a suburban park in Dadizele (Western Flanders, Belgium) (Fig. 1). The aim is to provide an estimate of the cost of the campaign (control, follow-up) and to review critical success factors and possible improvements.

In August 2005, bark stripping and cable gnawing were observed in a 5 ha suburban park, Mariënstede in Dadizele (50°51'5"N, 3°5'40"E), Belgium (Fig. 1, Online Resource 1). The damage was immediately linked to the occurrence of non-native squirrels first observed on 25/08/2005 and initially misidentified as Chinese rock squirrel *Sciurotamias davidianus* (MILNE-EDWARDS, 1867). To avoid further damage to the large ornamental trees in the park, it was decided to trap these squirrels. Mesh wire traps were placed near the trunks of large trees where and whenever squirrels were detected, baited with peanuts, walnuts or hazelnuts. Traps were checked daily in order to minimise detention time and impact on by-catch of non-target species. At this stage, animals were live trapped and kept in a bird and wild animal rehabilitation centre. An unexpectedly high number of 46 squirrels were removed from the site during the first 3 months. Despite continued trapping in 2006, sightings of squirrels in the park, surrounding gardens (9 ha) and a nearby abandoned amusement park (Dadipark; 9.5 ha) were still numerous. The number of squirrels trapped increased from about 100 individuals in 2006 to 130 by May 2007 (information from the municipality). It was acknowledged that the problem had been underestimated and further action was no longer affordable for the local manager of Mariënstede. Consequently, regional authorities, the Agency for Nature and Forest (ANB) and the Research Institute for Nature and Forest (INBO) were involved. Considering potential damage, exotic status and potential invasive behaviour, authorities and stakeholders quickly agreed on action. Since more damage was to be expected if the species expanded its range to other urban areas or forest ecosystems, it was concluded that full eradication of the population and subsequent follow-up were the appropriate response. All squirrels in the surroundings had to be tackled, including the private gardens and Dadipark. During a short trapping period in July

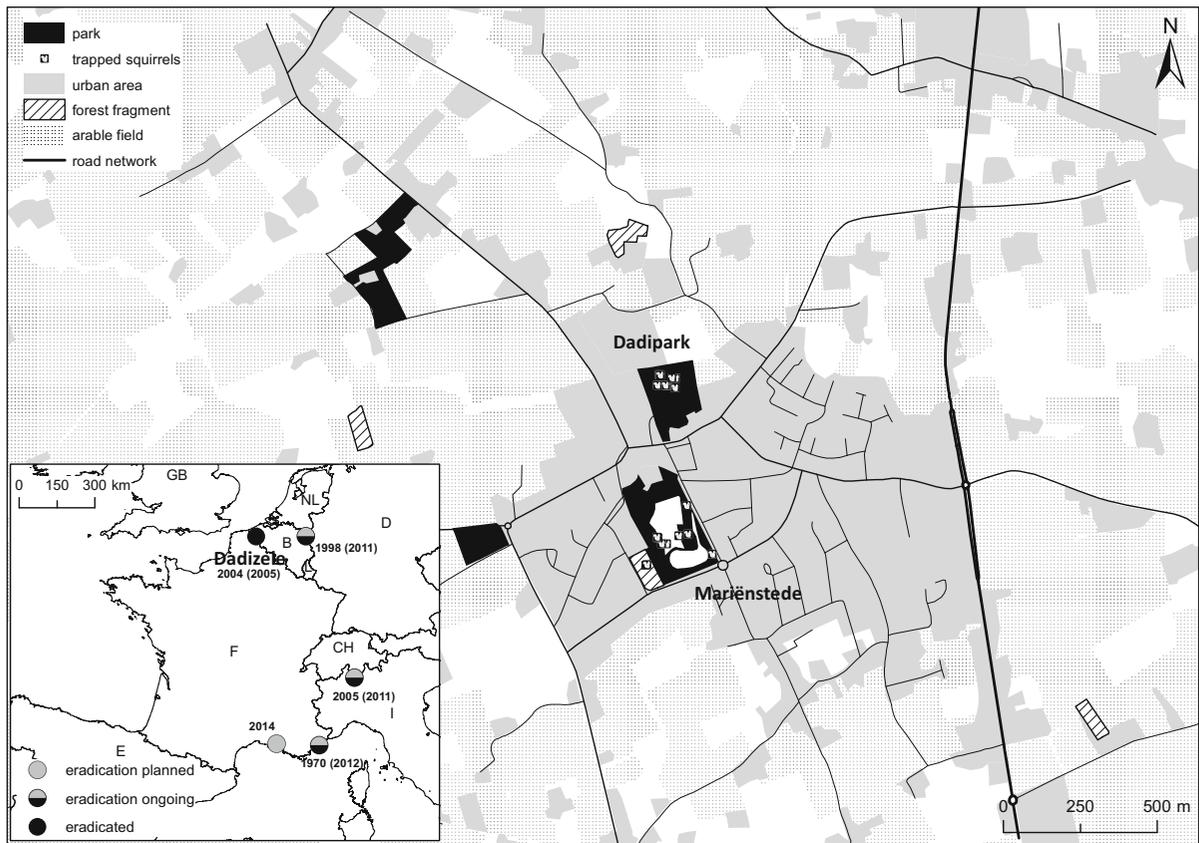


Fig. 1 *Inset*: occurrence and status of Pallas's squirrel *Callosciurus erythraeus* populations in Europe (NL The Netherlands, D Germany, B Belgium, F France, I Italy, CH Switzerland) with the year of introduction and the starting year of control between brackets. *Main map*: detailed location of Dadizele (western Flanders, Northern Belgium) with the local

suburban landscape configuration based on the Biological Valuation Map (Wils et al. 2006) and the locations of trapped squirrels between 15/03/2010 and 31/05/2010. Status of European populations is based on Chapuis et al. (2011, 2014), Dijkstra (2012), Mazzamuto et al. (2014) and pers. comm. L. Wauters

2007, 15 squirrels were removed from the area. From now on, captured animals were euthanized with an overdose of carbon dioxide in a certified mobile field unit and examined at INBO. The corpses were sexed, weighed, measured and dissected for data on general condition, diseases and reproductive status.

Based on the morphology of the skull and the male reproductive system (Online Resource 1) of the first trapped individuals we identified the species as *C. erythraeus*, a species native to southern China and mainland Southeast Asia (Moore 1959; Moore and Tate 1965). Species identity was confirmed by sequence analysis of two nuclear genes (C-myc and RAG1) using primer pairs S11/S9, S92/S91 and S70/S73 (Steppan et al. 2004). Subsequent homology

searches (NCBI megablast search) against other known sequences available in Genbank showed a best match with *C. erythraeus* for both C-myc (99.6 %) and RAG1 (99.2 %). Second best match was for the morphologically clearly distinguished *C. prevostii* (DESMAREST, 1822) (98 % at C-myc and RAG1), followed by *Sundasciurus philippinensis* (WATERHOUSE, 1839) (98 % at C-myc and 97 % at RAG1). The exact date of introduction in Dadizele is unclear. Based on reports of local people on squirrel occurrences, we estimate that the animals have been present for at least a year before the start of the management actions. The introduction pathway of the population is not known but most probably it originated from escaped animals of the abandoned zoo in the nearby

amusement park or from a nearby pet shop. Studies have shown that Pallas's squirrels disperse easily and can form populations from a very limited number of founders (Bertolino and Lurz 2013). Like other tree squirrel species, Pallas's squirrel has a high reproductive rate, a broad dietary range and plasticity to anthropogenic habitats (Bertolino and Lurz 2013). It can reach high densities and could therefore be a food competitor of native red squirrel *Sciurus vulgaris* L. and outcompete it. Furthermore, bark stripping by the species can be severe and cause damage to trees in forests, parks and tree plantations (Tamura and Ohara 2005). Meanwhile, Pallas's squirrel is established in Belgium, Japan, Argentina, France, Italy and The Netherlands (Bertolino and Lurz 2013; Dijkstra et al. 2009; Guichón and Doncaster 2008; Gurnell and Wauters 1999; Tamura et al. 1988). Pallas's squirrel is also a known carrier of several parasites (Dozières et al. 2010; Gozzi et al. 2013).

Based on this information it was decided to concentrate the trapping effort prior to the next breeding season. Trapping was conducted from February to April 2008. By the end of April 2008, we had caught an additional 78 squirrels. Further actions were suspended in the believe that the population was eradicated. After a period of 18 months without further sightings (until September 2009), squirrels were again reported in the park. Moultrie digital photo traps were installed to check for any remaining squirrels. Traps were deployed whenever there was any sign of squirrel presence. In successive years, the number of animals removed increased to 248 in total, and by January 2011, the last known animal was removed (Fig. 2).

Trapping effort was not constant. The trapping scheme consisted of five periods of trapping with a varied number of traps deployed (Table 1). Animals were caught using a minimum of 19 and a maximum of 44 (i.e. 4–9 traps per hectare) peanut or walnut baited mesh wire live traps (O'Farrell et al. 1994). Using maximum likelihood estimation from catch-effort data of the first capture campaign (Gould and Pollock 1997) we estimate initial population size at 47 (44.5; 48.8) squirrels, under an assumed constant catchability coefficient of 0.0028 (0.0016; 0.0039). This corresponds with an estimated initial density of 3.1 (3;3.3 95 % CI) squirrels ha^{-1} in the 15 ha park. These are rather low densities compared to reported densities of *C. erythraeus* elsewhere in its invasive range

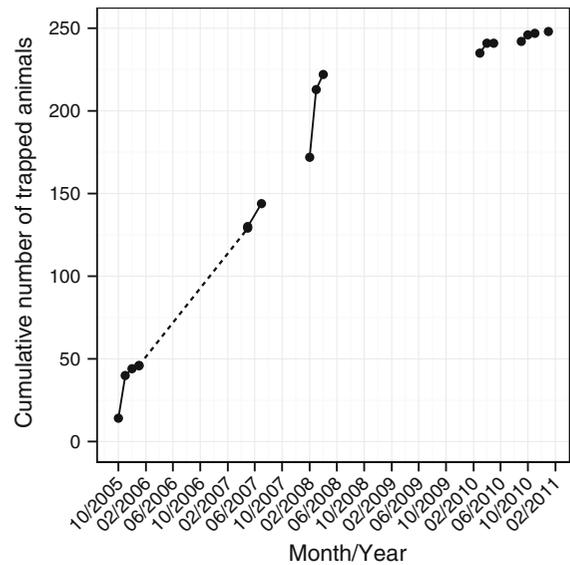


Fig. 2 Cumulative number of Pallas's squirrels caught per trimester in Dadizele during consecutive capture campaigns between October 2005 and January 2011. For the period Feb 2006–Apr 2007 (dashed line) monthly data are lacking

(Bertolino and Lurz 2013), indicating this population was probably in the early stages of invasion. The species is able to achieve population densities up to 18 individuals/hectare in a similar biotope in their invasive range (Benitez et al. 2013). Based on the maximum number of squirrels trapped in a single trapping period (84), density in the park was 5.6 squirrels ha^{-1} in 2006–2007 on average, which is considerably higher than previously reported average density ($0.28 \pm 0.25 \text{ ha}^{-1}$) of native red squirrel *S. vulgaris* in the same fragmented landscape setting in Belgium (Verbeylen et al. 2003). Densities of native red squirrel in other countries are usually also <1 individual ha^{-1} with peaks up to 1.6 ha^{-1} in mixed broadleaf woodland (Gurnell 1987). Our results indicate the population was successively depleted following a series of bottlenecks caused by consecutive trapping campaigns. Post-eradication surveillance was continued until June 2012 using photo traps (type SpyPoint IR-8, Moultrie and Reconyx HC600), bait points, baited nest boxes, interviews with locals and regular visual inspections for squirrels or traces of bark stripping on site. No evidence of the presence of squirrels has been found since January 2011.

Several studies have addressed the relative importance of different factors explaining eradication

Table 1 Start and end date of capture campaigns in Dadizele, executor of trapping (ANB Agency for Nature and Forest, INBO Research Institute for Nature and Forest), average

number of traps placed (# traps), number of animals caught (# animals), sex ratio (SR) of the trapped animals based on the number of investigated animals (M/F)

Start date	End date	Trapping	# Traps	# Animals	SR (M/F)
25/10/2005	14/01/2006	Mariënstede vzw	19	46	0.58 (16/27)
N/A	May/2007	Mariënstede vzw/Municipality	N/A	84	N/A
10/07/2007	23/07/2007	Mariënstede vzw/Municipality/ANB	30	15	1.17 (7/6)
25/02/2008	25/04/2008	Mariënstede vzw/Municipality/ANB	44	78	0.9 (36/40)
15/03/2010	31/05/2010	INBO	15	19	0.9 (9/10)
6/09/2010	26/11/2010	INBO	41	5	0.7 (2/3)
4/01/2011	3/03/2011	INBO	25	1	1 female
Total				248	0.82 (71/87)

success (Baker 2010; Myers et al. 2000; Pluess et al. 2012a, b). In this case, without addressing their relative importance, several of the preconditions for successful eradication were met:

- With little core habitat available to the squirrels and reacting quickly, the spatial extent of the invasion was relatively limited. Although unconfirmed sightings of squirrels were reported 5 km from the site, the Dadizele case illustrates that even on the continental scale some populations can have the characteristics of an island population because of the isolated nature of the habitat at hand and the relatively low permeability of the surrounding landscape matrix (in this case mostly arable fields, Fig. 1) for the species. This is in line with previous findings on the low perceptual range of Pallas's squirrel, which limits their ability to cross gaps in fragmented landscapes with low densities of connective features (Bridgman et al. 2012). Similarly, some landscape features might act as barriers to squirrel dispersal, for example the A8 motorway initially represented a barrier to the spread of the Cap d' Antibes (France) population (Chapuis et al. 2011). In this respect, eradication of populations might in many cases be a more feasible option than expected.
- Native red squirrels have never been reported in the area, so non-target impact on other squirrel species could be ruled out. The eradication was relatively small-scale, which limits the potential for non-target impacts (Myers et al. 2000). Sporadically, European hedgehog *Erinaceus europaeus* L., great tit *Parus major* L., Eurasian jay *Garrulus glandarius* L. and brown rat *Rattus*

norvegicus (BERKENHOUT, 1769) were caught in the traps. Since life-trapping was applied, by-catch was always released alive.

- Response to the outbreak was timely. There is a paucity of data on the reaction time regarding successful eradication of exotic vertebrate species, but for plants and invertebrates eradication is likely if attempted within 4 years after discovery (Pluess et al. 2012b). Pluess et al. (2012b) further concluded that the spatial extent of the invasion is related to the eradication outcome, with local campaigns being more successful than regional or national campaigns. In the case of Dadizele, the exact date of introduction was not known, yet reaction time was no longer than 1.5 years. However, this time lag, and the initial misidentification of the species, illustrate that even in densely urbanized areas the establishment of an alien species can sometimes be initially unobserved or not recognized as potentially problematic. The number of squirrels caught during the first capture campaign surprised many of the officials involved, indicating an underestimation of the population size and suggesting a low detectability of the species.
- Like many squirrel species, the species is easily attracted to baiting stations, making the animals susceptible to a low-tech control procedure and offering control prospects using basic natural history of the taxon rather than detailed knowledge of the target species biology (cf. Simberloff 2003).
- In this case, after an initial set-up phase, sufficient resources were allocated to conclusion of the action, including a notable investment of 1.5 years post-

eradication surveying with regular control on site using a range of different surveillance methods. Costing invasive mammal eradications is often difficult because variable costs have a substantial impact on the actual cost of any campaign (Donlan and Wilcox 2007). Thus, the estimate provided here cannot simply be extrapolated to other cases based on the extent of invasion. Some costs (e.g. communication, coordination) are necessary irrespective of the number of animals. Other costs (transport, human resources) are specific to the context of this particular eradication. However, with the relatively low cost of materials needed for trapping and euthanasia, most of the costs involved labour (Table 2). The cost of despatching to a rehabilitation centre and sterilizing the animals during the early campaigns are undocumented and not included in this overview. Although the cost of labour reported here was high, part of the work was embedded in the regular tasks of persons involved. Also, since 2007 the project was largely run as a science project on existing capacity and infrastructure of the research institute involved, limiting additional expenses. Therefore the actions were not perceived as a heavy extra financial burden by stakeholders or the local authority. Perseverance of the project coordinators and trappers was equally crucial, as wiping out the population took several repeated intensive trapping events, with intermittent periods of apparent zero-occurrence of squirrels and subsequent disillusion when animals were still present.

- With the amusement park closed in 2002 and absence of Pallas's squirrels in the nearby pet shop, the likelihood of reinvasion was low.
- The lines of authority became clear from 2007 on, with regional and local government agency officials agreeing on control targets, contributing with personnel and smoothing the process of obtaining authorization and permits. Approval for the action was signed by the competent Minister. Moreover, the responsible senior scientist worked in close cooperation with the trappers, generating both exchange of knowledge and ideas with managers in the field as well as a clear insight into trapping effort and organisation.

Although the reaction time was short and the extent of the invasion was limited, the campaign took 5 years

and required considerable resources. The first two capture campaigns, executed by local people, lacked coordination and experience (e.g. type of traps and baits to use) and trapping was often not a priority for the people involved. The long duration of this eradication and the problems encountered during the initial phase were reminiscent to the lack of a coordinated rapid response mechanism. The fourth campaign (Feb–Apr 2008) was ended prematurely. Also, the consistency of reporting on catch effort could be improved.

Apart from inadequate legal basis, lack of awareness and unclear responsibilities, the opposition of animal rights groups and lack of public support for lethal methods is also frequently reported as a bottleneck for successful removal of popular species like squirrels (Bertolino 2008; Bertolino and Genovesi 2003; Genovesi and Bertolino 2001). Therefore, in Dadizele, in the initial phase (2005), removed squirrels were brought to a bird and wild animal rehabilitation centre. An unknown number of squirrels was said to be sterilized and placed in a zoo in the Netherlands. This strategy is currently still being followed in the eradication campaign in Weert, the Netherlands, where non-lethal despatching of caught animals was a prerequisite for actions (pers. comm. S. Smolders). In Dadizele however, with the number of captures increasing steeply, the strategy quickly switched to humane killing without notable negative public response. Unlike other control campaigns on exotic squirrels in urban settings, such as the Life + project EC-SQUARE in Genoa Nervi urban park aiming at removing the single population of American grey squirrel *S. carolinensis* from Liguria (Italy) (van Ham et al. 2013), the actions were consciously kept low profile and opposition by the public was limited. However, before engaging in trapping, political support was gained through a permission of the High Council of Nature Conservation and a written statement of the Minister of the environment. Local people were informed of the actions through a message from the town council in the local newspaper and there was a clear communication line to a contact person in the town hall in case of any inquiries. It has been noted that eradication projects that have been initiated by people at the local level, can have full local support and achieve success with little negative public response (Sheail 2003).

Table 2 Documentation of the estimated cost of Pallas's squirrel *Callosciurus erythraeus* eradication in Dadizele (Northern Belgium)

Activity	Human resources	Equipment and materials
<i>Coordination</i>		
Meetings	€3.428 ^a	
Genetic analysis for species ID	€370	€150
Preparation and coordination	€42.630 ^b	
Communication	€500 ^c	
<i>Trapping</i>		
Life traps		€5874 ^f
Bait		€3.770 ^g
Transport		€11.500 ^h
Trapping	€103.970 ^d	
<i>Despatching of animals</i>		
Mobile field unit		€21.850 ⁱ
Isoflurane evaporator		€1.500
Carbon dioxide		€20
<i>Post-eradication surveying</i>		
Nest boxes		€200
Wildlife cameras		€5.000 ^j
Labour	€6.200 ^e	
Total cost	€157.098	€49.864

The cost of despatching to a rehabilitation centre and sterilizing the animals during the early campaigns are not included in this overview. Details of calculation are shown below

^a Estimate of meeting cost based on duration and number of people present per meeting using the average of outcomes from two online cost calculators (<http://www.effectivemeetings.com/diversions/meetingcost.asp> and <http://meetingking.com/meeting-cost-calculator/>), based on an average day rate of €426 and €185 for high-level and regular meetings respectively, ^b Based on number of senior scientist working days at a €426 day rate basis, ^c Estimate based on communications officer working time and printing cost of municipal leaflet, ^d Based on actual number of trapping days in the periods Oct 2005–Jan 2006 and May 2007–Jan 2011; for the period Feb 2006–Apr 2007 estimation is based on extrapolation from the number of squirrels caught and number of working days needed in the other capture campaigns à 1 field assistant at a €185 day rate, ^e Based on the number of survey days à 1 field assistant at a €185 day rate, ^f Cost of materials and number of working days needed for assembly à €185 day rate, ^g Bait à €3.38/kilo, ^h 32,800 km à €0.35/km, ⁱ ford transit catalogue price, ^j 10 Reconyx HC600 wildlife cameras with memory cards, security enclosure, lock and batteries

The Dadizele case clearly shows that the public should be made more aware on IAS related problems and the pet trade issue and that every report of alien squirrels should receive proper attention. Furthermore, as soon as a problem is detected, the difficult process of achieving a consensus amongst stakeholders and getting political and public support must be initiated (Bertolino and Lurz 2013). Also, the practicalities of swift eradication require the provision of a contingency fund and clear protocols for actions at local and regional level. Ideally, management should be backed by actions aiming at preventing reinvasion. Pallas's squirrel does not occur on the positive list of mammals

that can be kept as a pet in Belgium by private people (Royal Decree of 7 December 2001, updated on 16 July 2009). Also, the release of exotic animals in the wild is forbidden by law in all Belgian regions. Despite this, establishment of the Dadizele population was still possible, indicating these legislative instruments are not comprehensive tools in preventing new introductions. With a comprehensive risk assessment for Belgium now available (Schockert 2012), we advocate a trade ban with thorough enforcement as a preventive measure to reduce the risk of this species becoming established. A trade ban has already been in place in The Netherlands since November 2009 and in

Italy since 2013 (Bertolino et al. 2013). The species was also included in an early warning initiative in Belgium involving citizen science and volunteer recorders (<http://waarnemingen.be/exoten>).

Since September 2012, the updated EU Wildlife Trade Regulation (338/97/EC, Implementing Regulation 757/2012) has suspended the introduction of live specimens of Pallas's squirrel, grey squirrel *S. carolinensis* GMELIN, 1788 and fox squirrel *S. niger* L. in the EU because they represent a threat to indigenous species and ecosystems. Populations of non-native squirrels mostly originate from intentional importation of live animals that are bred in zoos or kept as pets and subsequently escape (Bertolino 2008, 2009; DAISIE 2009). Only four established populations of Pallas's squirrel now remain in Europe (Cap d'Antibes and Bouches du Rhône, France; Weert, The Netherlands; Brezzo di Bedero, Italy) and control campaigns are either ongoing or planned for all of these (Chapuis et al. 2011, 2014; Dijkstra 2012; Mazzamuto et al. 2014) (Fig. 1). Adding Pallas's squirrel (and other potentially invasive tree squirrels) to the list of species of EU or member state concern currently under development for the new European Union Regulation No 1143/2014 on the prevention and management of the introduction and spread of IAS (European Union 2014), should provide an incentive to minimise escapes and subsequent establishment, and consequent impact, of this tree squirrel at the continental scale.

Acknowledgments We wish to thank the municipality of Dadizele, the site owner and gardener at Mariënstede, and officials of the Agency for Nature and Forest who were supportive of the campaign and who assisted in the field work. We thank Joachim Mergey for information on the megablast seach. We are grateful to Riccardo Scalera, Simon Baker and two anonymous reviewers for comments on an earlier version of this manuscript. We thank Hugo Verreycken for providing references on successful fish eradications in Europe and Luc Wauters for information on the eradication of Pallas's squirrel in Italy. Part of this work was performed within the framework of the EU co-funded Interreg 2Seas project RINSE (Reducing the Impact of Non-Native Species in Europe) (www.rinse-europe.eu) (2012–2014), which seeks to improve awareness of the threats posed by INNS, and the methods to address them.

References

- Baker S (2010) Control and eradication of invasive mammals in Great Britain. *Rev Sci Tech* 29:311–327
- Benitez VV, Almada Chavez S, Gozzi AC, Messetta ML, Guichón ML (2013) Invasion status of Asiatic red-bellied squirrels in Argentina. *Mamm Biol* 78:164–170. doi:10.1016/j.mambio.2012.10.002
- Bertolino S (2008) Introduction of the American grey squirrel (*Sciurus carolinensis*) in Europe: a case study in biological invasion. *Curr Sci* 95:903–906
- Bertolino S (2009) Animal trade and non-indigenous species introduction: the world-wide spread of squirrels. *Divers Distrib* 15:701–708. doi:10.1111/j.1472-4642.2009.00574.x
- Bertolino S, Genovesi P (2003) Spread and attempted eradication of the grey squirrel (*Sciurus carolinensis*) in Italy, and consequences for the red squirrel (*Sciurus vulgaris*) in Eurasia. *Biol Conserv* 109:351–358. doi:10.1016/S0006-3207(02)00161-1
- Bertolino S, Lurz PW (2013) *Callosciurus* squirrels: worldwide introductions, ecological impacts and recommendations to prevent the establishment of new invasive populations. *Mammal Rev* 43:22–33. doi:10.1111/j.1365-2907.2011.00204.x
- Bertolino S, Balduzzi A, Martinoli A, Carlini A, Carnevale P, Picco L, Rossi EM (2013) Banning squirrels from the pet trade in Italy. *Aliens Newsl* 33:44
- Bomford M, O'Brien P (1995) Eradication or control for vertebrate pests? *Wildl Soc B* 23:249–255
- Bremner A, Park K (2007) Public attitudes to the management of invasive non-native species in Scotland. *Biol Conserv* 139:306–314. doi:10.1016/j.biocon.2007.07.005
- Bridgman LJ, Benitez VV, Grilli MG, Mufato N, Acosta D, Guichón ML (2012) Short perceptual range and yet successful invasion of a fragmented landscape: the case of the red-bellied tree squirrel (*Callosciurus erythraeus*) in Argentina. *Landsc Ecol* 27:633–640. doi:10.1007/s10980-012-9727-2
- Britton J, Brazier M (2006) Eradicating the invasive topmouth gudgeon, *Pseudorasbora parva*, from a recreational fishery in northern England. *Fish Manag Ecol* 13:329–335. doi:10.1111/j.1365-2400.2006.00510.x
- Britton JR, Davies GD, Brazier M (2010) Towards the successful control of the invasive *Pseudorasbora parva* in the UK. *Biol Invasions* 12:125–131. doi:10.1007/s10530-009-9436-1
- Caffrey JM, Acevedo S, Gallagher K, Britton R (2008) Chub (*Leuciscus cephalus*): a new potentially invasive fish species in Ireland. *Aquat Invasions* 3:201–209. doi:10.3391/ai.2008.3.2.11
- CBD (1992) Convention on biological diversity, Rio de Janeiro, Argentina. <http://www.biodiv.org/convention/>
- Chapuis JL, Dozières A, Pisanu B, Gerriet O, Berlin S, Pauvert S (2011) Plan national de lutte relatif à l'écureuil à ventre rouge (*Callosciurus erythraeus*) dans les Alpes-Maritimes. Muséum National d'Histoire Naturelle, Paris, Muséum d'Histoire Naturelle de Nice, DREAL Provence-Alpes-Côte d'Azur
- Chapuis JL, Gerriet O, Pisanu B, Pauvert S (2014) Plan national de lutte relatif à l'écureuil à ventre rouge (*Callosciurus erythraeus*) dans les Alpes-Maritimes: bilan et perspectives. Muséum National d'Histoire Naturelle, Paris, Muséum d'Histoire Naturelle de Nice, DREAL Provence-Alpes-Côte d'Azur. http://ecureuils.mnhn.fr/sites/default/files/documents/plan_evr_bilan_2012-2014_et_perspectives_2015-2018.pdf. Accessed 25 Mar 2015

- DAISIE (2009) Handbook of alien species in Europe. Springer, Netherlands
- Dijkstra V (2012) Notitie wegvangactie Pallas' eekhoorn Weert, fase 2. Zoogdierverseniging, Arnhem
- Dijkstra V, Overman W, Verbeylen G (2009) Inventarisatie Pallas' eekhoorn bij Weert. Zoogdierverseniging, Arnhem, Netherlands. https://www.vva.nl/txmpub/files/?p_file_id=2001527
- Donlan CJ, Wilcox C (2007) Complexities of costing eradications. *Anim Conserv* 10:154–156. doi:10.1111/j.1469-1795.2007.00101.x
- Dozières A, Pisanu B, Gerriet O, Lapeyre C, Stuyck J, Chapuis JL (2010) Macroparasites of Pallas's squirrels (*Callosciurus erythraeus*) introduced into Europe. *Vet Parasitol* 172:172–176. doi:10.1016/j.vetpar.2010.04.021
- Drolet D, Locke A, Lewis MA, Davidson J (2014) User-friendly and evidence-based tool to evaluate probability of eradication of aquatic non-indigenous species. *J Appl Ecol* 51(4):1050–1056. doi:10.1111/1365-2664.12263
- Drolet D, Locke A, Lewis MA, Davidson J (2015) Evidence-based tool surpasses expert opinion in predicting probability of eradication of aquatic nonindigenous species. *Ecol Appl* 25(2):441–450. doi:10.1890/14-0180.1
- Esler KJ, Prozesky H, Sharma GP, McGeoch M (2010) How wide is the “knowing-doing” gap in invasion biology? *Biol Invasions* 12:4065–4075. doi:10.1007/s10530-010-9812-x
- European Union (2014) Regulation (EU) no 1143/2014 of the European parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. *Official Journal of the European Union* 4.11.2014, L317: 35–55
- Genovesi P (2005) Eradications of invasive alien species in Europe: a review. *Biol Invasions* 7:127–133. doi:10.1007/1-4020-3870-4_12
- Genovesi P (2007) Limits and potentialities of eradication as a tool for addressing biological invasions. In: Nentwig W (ed) *Biological invasions ecological studies*, vol 193. Springer, Heidelberg, pp 385–402
- Genovesi P, Bertolino S (2001) Human dimension aspects in invasive alien species issues: the case of the failure of the grey squirrel eradication project in Italy. In: McNeely JA (ed) *The Great reshuffling: human dimensions of invasive alien species*. IUCN, Gland, pp 113–119
- Genovesi P, Carnevali L (2011) Invasive alien species on European islands: eradications and priorities for future work on Island invasives. In: Veitch CR, Clout MN, Towns DR (eds) *Island invasives: eradication and management*. IUCN, Gland, pp 56–62
- Genovesi P, Scalerà R, Brunel S, Roy D, Solarz W (2010) Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe. *Eur Environ Agency Cph*. doi:10.2800/4167
- Gosling LM, Baker SJ (1989) The eradication of muskrats and coypus from Britain. *Biol J Linn Soc* 38:39–51. doi:10.1111/j.1095-8312.1989.tb01561.x
- Gould W, Pollock K (1997) Catch-effort maximum likelihood estimation of important population parameters. *Can J Fish Aquat Sci* 54:890–897. doi:10.1139/f96-327
- Gozzi AC, Guichón ML, Benitez VV, Romero GN, Auteri C, Brihuega B (2013) First isolation of *Leptospira interrogans* from the arboreal squirrel *Callosciurus erythraeus* introduced in Argentina. *Wildl Biol* 19:483–489. doi:10.2981/13-051
- Guichón ML, Doncaster CP (2008) Invasion dynamics of an introduced squirrel in Argentina. *Ecography* 31:211–220. doi:10.1111/j.0906-7590.2008.5308.x
- Gurnell J (1987) *The natural history of squirrels*. Helm, London
- Gurnell J, Wauters L (1999) *Callosciurus erythraeus*. In: Mitchell-Jones AJ (ed) *The atlas of European mammals*. Academic Press, London, pp 182–183
- Howald G, Donlan CJ, Galván JP, Russell JC, Parkes J, Samaniego A, Wang Y, Veitch D, Genovesi P, Pascal M, Saunders A, Tershy B (2007) Invasive rodent eradication on islands. *Conserv Biol* 21:1258–1268. doi:10.1111/j.1523-1739.2007.00755.x
- Keitt B, Campbell K, Saunders A, Clout M, Wang Y, Heinz R, Newton K, Tershy B (2011) The global islands invasive vertebrate eradication database: a tool to improve and facilitate restoration of island ecosystems. In: Veitch CR, Clout MN, Towns DR (eds) *Island invasives: eradication and management*. IUCN, Gland
- Martins T, Brooke MdL, Hilton G, Farnsworth S, Gould J, Pain D (2006) Costing eradications of alien mammals from islands. *Anim Conserv* 9:439–444. doi:10.1111/j.1469-1795.2006.00058.x
- Mazzamuto MV, Panzeri M, Sonzogni D, Su H, Spada M, Wauters LA, Preatoni DG, Martinoli A (2014) Tell me your habitat and I'll tell your future. A contribution to the assessment of expansion potential of introduced *Callosciurus erythraeus*. *Hystrix. It J Mamm* 25(supplement):21
- Moore J (1959) Relationships among the living squirrels of the Sciurinae. *B Am Mus Nat Hist* 118:153–206
- Moore J, Tate GHH (1965) A study of the diurnal squirrels: sciurinae, of the Indian and Indochinese subregions. *Chic Nat Hist Mus*. doi:10.5962/bhl.title.2919
- Moore N, Roy S, Helyar A (2003) Mink (*Mustela vison*) eradication to protect ground-nesting birds in the Western Isles, Scotland, United Kingdom. *New Zeal J Zool* 30:443–452. doi:10.1080/03014223.2003.9518351
- Myers JH, Simberloff D, Kuris AM, Carey JR (2000) Eradication revisited: dealing with exotic species. *Trends Ecol Evol* 15:316–320. doi:10.1016/S0169-5347(00)01914-5
- Naidoo R, Balmford A, Ferraro PJ, Polasky S, Ricketts TH, Rouget M (2006) Integrating economic costs into conservation planning. *Trends Ecol Evol* 21:681–687. doi:10.1016/j.tree.2006.10.003
- O'Farrell MJ, Clark WA, Emmerson F, Juarez SM, Kay FR, O'Farrell TM, Goodlett TY (1994) Use of a mesh live trap for small mammals: Are results from Sherman live traps deceptive? *J Mammal* 75:692–699
- Pluess T, Cannon R, Jarošík V, Pergl J, Pyšek P, Bacher S (2012a) When are eradication campaigns successful? A test of common assumptions. *Biol Invasions* 14:1365–1378. doi:10.1007/s10530-011-0160-2
- Pluess T, Jarošík V, Pyšek P, Cannon R, Pergl J, Breukers A, Bacher S (2012b) Which factors affect the success or failure of eradication campaigns against alien species? *PLoS ONE* 7:e48157. doi:10.1371/journal.pone.0048157
- Robertson P, Adriaens T, Caizergues A, Cranswick PA, Devos K, Gutiérrez-Expósito C, Henderson I, Hughes B, Mill AC, Smith GC (2015) Towards the European eradication of the

- North American ruddy duck. *Biol Invasions* 17:9–12. doi:[10.1007/s10530-014-0704-3](https://doi.org/10.1007/s10530-014-0704-3)
- Rouland P (1985) Les castors canadiens de la Puisaye. *Bull Mens Off Natl Chasse* 91:35–40
- Schockert V (2012) Risk analysis of the Pallas's squirrel, *Callosciurus erythraeus*. Risk analysis report of non-native organisms in Belgium. Service Public de Wallonie Editions. <http://share.bebif.be/data/ias/Risk%20analyses/Callosciurus%20erythraeus.pdf>
- Sheail J (2003) Government and the management of an alien pest species: a British perspective. *Landsc Res* 28:101–111. doi:[10.1080/01426390306528](https://doi.org/10.1080/01426390306528)
- Simberloff D (2003) How much information on population biology is needed to manage introduced species? *Conserv Biol* 17:83–92. doi:[10.1046/j.1523-1739.2003.02028.x](https://doi.org/10.1046/j.1523-1739.2003.02028.x)
- Simberloff D (2009) We can eliminate invasions or live with them. Successful management projects. *Biol Invasions* 11:149–157. doi:[10.1007/s10530-008-9317-z](https://doi.org/10.1007/s10530-008-9317-z)
- Steppan SJ, Storz BL, Hoffmann RS (2004) Nuclear DNA phylogeny of the squirrels (Mammalia: Rodentia) and the evolution of arboreality from c-myc and RAG1. *Mol Phylogenet Evol* 30:703–719. doi:[10.1016/S1055-7903\(03\)00204-5](https://doi.org/10.1016/S1055-7903(03)00204-5)
- Tamura N, Ohara S (2005) Chemical components of hardwood barks stripped by the alien squirrel *Callosciurus erythraeus* in Japan. *J For Res* 10:429–433. doi:[10.1007/s10310-005-0162-y](https://doi.org/10.1007/s10310-005-0162-y)
- Tamura N, Hayashi F, Miyashita K (1988) Dominance hierarchy and mating behavior of the Formosan squirrel, *Callosciurus erythraeus taiwanensis*. *J Mammal* 69:320–331. doi:[10.2307/1381382](https://doi.org/10.2307/1381382)
- Temple SA (1990) The nasty necessity: eradicating exotics. *Conserv Biol* 4:113–115. doi:[10.1111/j.1523-1739.1990.tb00096.x](https://doi.org/10.1111/j.1523-1739.1990.tb00096.x)
- van Ham C, Genovesi P, Scalera R (2013) Invasive alien species: the urban dimension, case studies on strengthening local action in Europe. IUCN, Brussels, Belgium. <https://portals.iucn.org/library/efiles/documents/2013-027.pdf>
- Verbeylen G, De Bruyn L, Matthysen E (2003) Patch occupancy, population density and dynamics in a fragmented red squirrel *Sciurus vulgaris* population. *Ecography* 26:118–128. doi:[10.1034/j.1600-0587.2003.03236.x](https://doi.org/10.1034/j.1600-0587.2003.03236.x)
- Williams FE, Eschen R, Harris A, Djeddour DH, Pratt CF, Shaw RS, Varia S, Lamontagne-Godwin JD, Thomas SE, Murphy ST (2010) The economic cost of invasive non-native species on Great Britain. CABI Europe, Egham
- Wils C, Paelinckx D, Adams Y, Berten B, Bosch H, De Knijf G, De Saeger S, Demolder H, Guelinckx R, Lust P, Oosterlynck P, Scheldeman K, t'Jollyn F, Van Hove M, Vandebussche V, Vriens L (2006) Biologische Waarderingskaart van het Vlaamse Gewest. Instituut voor Natuur-en Bosonderzoek (INBO), Brussels