Reducing negative impacts on non-target species during grey squirrel (Sciurus carolinensis) control activities

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Summary:
There is limited information on the frequency of non-target captures during grey squirrel control operations in Europe. We present data from four control programmes and highlight the need for greater assessment of the negative impacts on a range of avian and mammalian species. The risk of inter-specific infection is investigated and opportunities to minimise non-target capture in both live-capture trap and kill-trap designs are explored.

Introduction

Invasive alien species have become one of the main drivers of biodiversity loss (Kumschick et al., 2015; Bellard et al., 2016), an impact often accompanied by significant costs incurred through environmental damage including native species declines (Gurnell et al., 2016). Management strategies developed to reduce these threats often require population control activities aimed at either spatially containing the target species or reducing population abundance to a level where negative impacts are limited (Bertolino et al., 2016). In certain cases, populations may be reduced to zero, achieving the local eradication of the invasive species (Robertson et al., 2016).

Small mammal control programmes typically use live-capture or kill-traps, the selectivity of which must be evaluated in terms of target species removal and possible impacts on non-target species (also known as a by-catch). Using non-selective trapping methods will increase the risk of catching non-target species and therefore reduce the probability of catching target species (Phillips and Winchell, 2011). Non-target captures also raise animal welfare (see Perry, 2004 for descriptive definitions) and conservation issues because of the potential negative physiological and fitness effects, and the potential risk of mortality (Short and Reynolds, 2001; Waldien et al., 2004; Stothart et al., 2016). If lethal trap designs are employed, then non-target species have a greater exposure to mortality or serious injury.

The eastern grey squirrel (*Sciurus carolinensis)* is a North American species introduced to some European countries where it competes with the native Eurasian red squirrel (*Sciurus vulgaris)* and damages forest trees (Mayle et al., 2007; Bertolino, 2008). Introduced populations are therefore the subject of wide-scale control programmes to reduce the negative impacts upon ecosystems and commercial forest activities (Bertolino et al., 2015; Gurnell et al., 2016; Schuchert et al., 2014). Control is typically conducted using live-trap designs (Gurnell and Pepper, 1993, 2016; Parrott et al., 2009; Shuttleworth et al., 2015a).

In the context of non-target species, Mayle et al. (2007) recommended that live-trapping should be the main method of grey squirrel control in preference to lethal spring-traps, which they describe as being 'less selective'. However, in the last decade, spring-trapping protocols have sought to improve selectivity through the integration of various tree mounted box designs; housings within which traps are set to limit non-target species access (see Dutton, 2016). Although it is best practice to inspect traps regularly each day, both target and non-target animals can often be confined within live-capture traps for protracted periods. Consequently, if spring-trap operators can preclude non-targets, this raises the question of whether, on the grounds of animal welfare, greater use should be made of spring-traps relative to live-capture trap designs because there is no lengthy confinement prior to dispatch. Interestingly, although Parrott et al. (2009) recommended that data on non-target captures should be recorded, to date these are not collected routinely in grey squirrel trapping programmes.

This paper examines data on target and non-target captures opportunistically collected across four grey squirrel control programmes. Three geographically discrete study areas deployed live-capture traps, often in areas where red squirrel was present. These included north Wales (including both the island of Anglesey and adjacent mainland areas in Gwynedd, UK) (Schuchert et al., 2014; Shuttleworth et al., 2015b), and also two Italian projects in the Piedmontese and Ligurian regions (see Martinoli et al., 2010; Bertolino et al., 2015, 2016) where animal welfare considerations have been the cornerstone of operational design. We review the frequency and potential risks to non-target species confined within live-capture traps, including inter-specific infection, and we then discuss future opportunities to limit impacts. The fourth study was a small-scale trial of Magnum 116 spring-traps set within modified wooden Fineren boxes in woodlands in Gwynedd where the red squirrel was absent. Box modifications had followed from earlier research indicating a need to further limit avian non-target species (see Shuttleworth et al., 2016a).

Methods

Live-capture traps (north Wales, UK)

Contractors and volunteers controlling grey squirrels on Anglesey and the adjacent mainland county of Gwynedd used Albi™ 079 single capture 'Mink traps' (175mm width x 600mm length x 150mm height) with entrance of 125 x 125mm. These were operated following established best practice guidance (Gurnell and Pepper, 1993; Powell and Proulx, 2003; Mayle et al., 2007; see Schuchert et al., 2014 for detailed methodology). Each cage was covered with black plastic and then leaf litter to protect and insulate animals from bad weather and temperature extremes (Bull et al., 1996; Gannon et al., 2007; Mayle et al., 2007). Covering also reduced the likelihood of an individual squirrel pushing their muzzle up through the roof panel and then becoming stuck after getting the upper incisors hooked over the mesh (see Jung and O'Donovan, 2005). Traps were typically set on the ground. If disturbed by badgers (*Meles meles)* or sheep (*Ovis aries)* they were set on platforms in trees. Traps were routinely baited with whole maize, and in some instances with sunflower seed. Diffuse baiting, where additional bait was broadcast in the immediate vicinity to draw in animals to the trap was used.

Where grey squirrels were known to be sympatric with red squirrels, each trap would typically be checked twice a day and frequently closed in the evening and reopened the following morning. In areas where the red squirrel was not known to occur, traps were checked once a day and would only be closed when the operator would not be undertaking inspections the following day. The risk that captured animals would be confined overnight was balanced against the need to maximise the probability of trapping declining numbers of grey squirrels present in the environment.

A trapping session was a discrete period during which a defined woodland geography was trapped, usually across two to four weeks, after which there would be an interval of several months before the woodland was revisited and trapping recommenced. Although trapping operations occurred from 1998-2013, non-target capture data are only available for periods between 2010 and 2013.

Live-capture traps (Italy)

The frequency of non-target captures during grey squirrel control in Italy, were gathered for two study areas: one in the Piedmont region and a second at Genoa Nervi in the Liguria region. Control activities were conducted in the framework of a European funded LIFE EC-SQUARE project in years 2012-2015 with Tomahawk Live traps (Collapsible model 202) covered with black plastic and baited with hazelnuts and walnuts. Bait was initially distributed also around the traps to draw the animals in. In Piedmont trapping was conducted in some small forests and private estates; red squirrels were either absent or present at very low density. Therefore, traps were opened in the morning, inspected once or twice a day and closed in the evening. In Liguria trapping was conducted in an urban park within a project involving capturing, surgically sterilizing and releasing the squirrels in another park of the city. In a first phase, when population density was

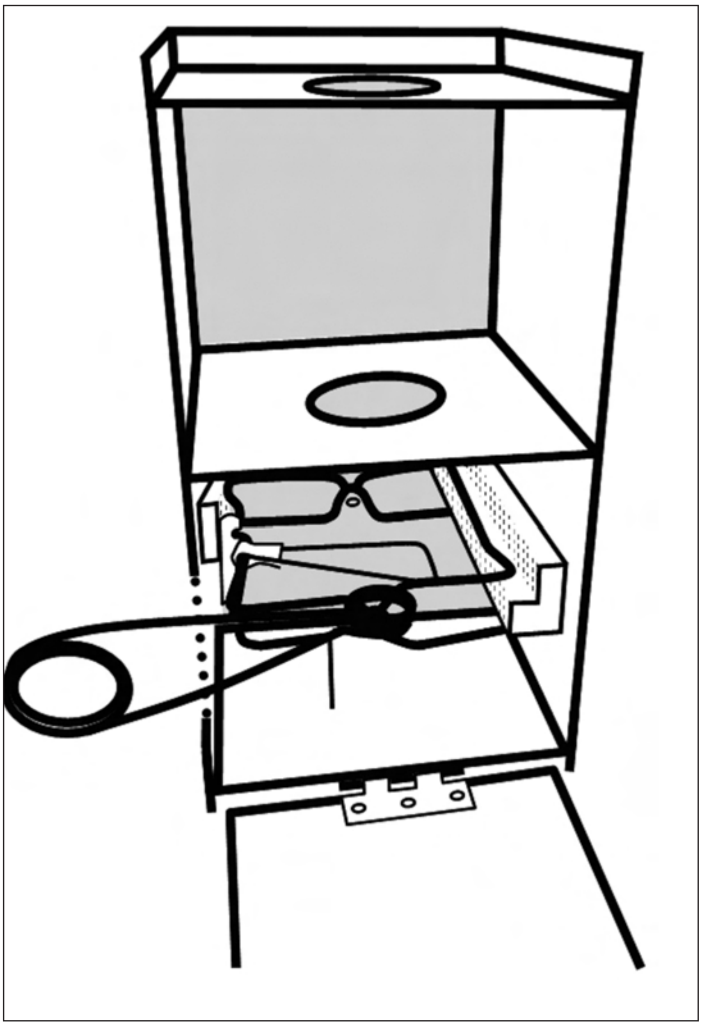

Figure 1. A magnum 116 trap set within a ply board construction (185mm width x 185mm depth x 335mm height) Fineren box. The trap is set on a wooden rail ensuring that it is set in a standard position. See Shuttleworth et al. (2016a) for a detailed description. (Image copyright: Van der Wall)

high, groups of traps were continuously kept under visual inspection by operators. In the second phase, traps were visually inspected every 10-15 min. This protocol was adopted to transfer the squirrels to the clinic as soon as possible, minimizing stress. In the Ligurian trapping area red squirrels were never present, but black rats (*Rattus rattus*) were common.

Magnum 116 spring-traps

The commercially available Fineren box (Figure 1) was modified to prevent access to the lower chamber in the box containing a rail mounted Magnum 116 spring-trap. Two 40mm x 70mm strips of black 0.7mm thick, corrugated Visqueen™ damp proof course (DPC) membrane were each fixed (using two or more 3mm staples) on the ceiling of the lower box chamber and at the edge of the 65mm diameter hole. Their rigidity meant that they could be positioned such that they almost touched in the middle of the hole and thus formed a horizontal visual and physical barrier (Figure 2a, b). Their flexibility meant that a grey squirrel would be able to push down through this 'curtain', and as the strips were bent vertically by the animals' passage, they were short enough not to touch the metal leaf trigger of the trap beneath. In this way, the trap could not be triggered prematurely as the animal moved down to access food on the box floor beneath the trap. Plastic tabs were occasionally chewed by grey squirrels and when moving Fineren boxes from one woodland to another, we replaced all partially chewed tabs even though they were still functional. When traps were in operation and a plastic tab was chewed so that its functional value was significantly degraded, the tab was replaced and this action recorded.

Between one and 16 modified Fineren box or boxes containing Magnum 116 traps were set in 11 woodlands in Gwynedd between March and June 2016. They were operated and baited as described in Shuttleworth et al. (2016a). All target and non-target catches were recorded.

Data analysis

Trapping effort was expressed in trap days, calculated as the number of traps set multiplied by the number of days trapping (irrespective of trap inspection frequency, or whether a trap was only opened during the day and closed at night, or left open throughout a 24 hour period). The number of grey squirrels and non-target species trapped were standardized as number of captures per 100 trap days.

Potential risks to animals caught in live-trap designs

Separately, we reviewed the range of injuries and negative impacts reported from published live-trapping studies. Since bacterial and viral infections might be deposited at live-capture traps, we reviewed the epidemiological literature for the species recorded in our European grey squirrel control case studies.

Results

Live-capture traps (UK)

Data from a total of 90,420 live-capture trap days were available from North Wales in the period 2010-2013. Grey squirrel, red squirrel and other animal species were caught at

Figure 2. Images of the flexible black plastic tabs in position (a, left) viewed from above (b, right) viewed from beneath. (Image copyright C.M. Shuttleworth)

Table 1. The cumulative capture rate recorded per 100 trap days for grey squirrels and non-target species in three live-trapping programmes.

Region	Capture rate per 100 trap days				Total trapping effort (trap days)
	Target Species	Non-target species			
	Grey squirrel	Red squirrel	Birds	Other mammals	
North Wales	1.89	1.37	1.51	1.44	90,420
Liguria	14.91	0.00	0.51	10.36	2,374
Piedmont	31.44	2.34	0.72	0.36	1,110

a rate of 1.89, 1.37 and 2.95 captures per 100 trap days (Table1). Other species included small passerines (0.93 per 100 trap days); hedgehog, *Erinaceus europaeus* (0.69); brown rat (0.65); pheasant, *Phasianus colchicus* (0.27); corvid species (0.25); rabbit, *Oryctolagus cuniculus* (0.07); woodpigeon, *Columba palumbus* (0.03); stoat/polecat, *Mustela erminea/Mustela putorius* (furo) (mustelids) (0.02); greater spotted woodpecker, *Dendrocopos major* (0.02); unrecorded duck species (<0.01), red fox (cubs); *Vulpes vulpes* (<0.01); domestic or feral cat, *Felis catus* (<0.01) and wood mouse, *Apodemus sylvaticus* (<0.01). Recorded corvid species included carrion crow, *Corvus corone;* jackdaw, *Corvus monedula;* magpie, *Pica pica* and jay, *Garrulus glandarius*. The species of small passerine were not recorded consistently and included blackbird, *Turdus merula;* robin, *Erithacus rubecula;* chaffinch, *Fringilla coelebs;* nuthatch, *Sitta europaea* and great tit, *Parus major*.

Live-capture traps (Italy)

In the Liguria region a total of 2,374 trap days were recorded. Grey squirrel and other animal species were caught at a rate of 14.91 and 10.87 captures per 100 trap days respectively (Table1). Other species included black rats (10.36 captures per trap day) corvids (0.08) and small passerines (0.42).

Table 2. Potential impacts to non-target species caught in live-capture traps.

	Direct impact	Indirect or subsequent impacts	Reference
Injuries	Loss or damage to flight feathers; Damage to claws and teeth; Skeletal and muscle damage.	Reduced foraging efficiency; Greater vulnerability to predation.	Baumgartner (1940), Wadian et al. (2004), Woodroffe et al. (2005), Byrne et al. (2015)
	Abrasions and cuts to upper beak (cere), top of the head, muzzle and or limbs.	Elevated risk of future bacterial infection; Reduced foraging efficiency.	Powell & Proulx (2003), Wadian et al. (2004), Woodroffe et al. (2005), Byrne et al. (2015)
	Ocular damage	Greater vulnerability to predation; Reduced foraging efficiency.	Iossa et al. (2007)
	Amputation of limbs	Death; Reduced foraging efficiency; Greater vulnerability to predation.	Wadian et al. (2004)
Inter-specific infection		Elevated inter-specific infection risk from soiled traps.	Everest et al. (2014)
Confinement duration	Stress or shock	Reduced foraging efficiency; Vulnerability to predation whilst confined; Physiological impacts.	Wadian et al. (2004), Stothart et al. (2016)
	Inability to access and care for dependent young; Inability to access natal nest.	Retarded growth offspring rates; higher mortality risk of young.	Wadian et al. (2004)
	Disorientation		Washington Department of Fish & Wildlife (undated)
	Dehydration	Death	Schemnitz et al. (2009)
	Hypothermia	Death	Bull et al. (1996)
Predation	Killed or injured by a predator whilst confined.	Death	Shuttleworth et al. (2016b)
Access supplemental food (trap bait)	Initial energetic gain.	Consumption of bait may reduce attraction to trap of target species.	Barnett & Dutton 1995

In the Piedmont region a total of 1,110 trap days were recorded. Grey squirrel, red squirrel and other animal species were caught at a rate of 31.44, 2.34 and 1.08 captures per 100 trap days (Table 1). Other species included hedgehog (0.36 captures per trap day), greater spotted woodpecker (0.36), and small passerines (0.36). All animals of non-target species were released unharmed.

Magnum 116 spring-traps

A total of 496 trap days were recorded with Magnum 116 traps set within modified Fineren box traps. Seventy two grey squirrels (14.52 per 100 trap days) and a single wood mouse (0.2) were caught. Grey squirrels were all dead when traps were inspected. Although no grey squirrels were found alive, in one instance an animal had been caught by the hind leg and there was extensive chewing of the box timber. Grey squirrels chewed at the plastic tabs, and on 12 occasions the damage was sufficient for tab replacement.

A live wood mouse and a bank vole (*Myodes glareolus*) were observed within the lower chamber of the box on separate occasions. They had not triggered the traps. There were no occasions when traps were found sprung without any animal caught.

Risks associated with live-trapping operations

Potential negative impacts associated with confinement within live-capture trap designs include direct physical and fitness effects (Table 2). Potential pathogenic inter-specific infections that pose a threat to protected species such as the red squirrel and also to other non-targets in and around traps are given in Table 3 and provide an important health risk context.

Table 3. Potential intra-specific and inter-specific infections that may be shared at traps or other point food sources.

Species	Infection/agent	Inter-specific risk	Reference
Corvids (*Corvus* spp.)	Reovirus	Magpie Raven	Lawson et al. (2015) Everest (unpubl. obs.)
Small passarines (*Passeriform* spp.)	Salmonellosis, Campylobacteriosis, Enterobactericiae, Cocci infections.		http://www.defra.gov.uk/ahvla-en/files/pub-gbwsp.pd Lawson et al. (2014), Harris et al. (2014)
	Toxoplasmosis		Simpson et al. (2013)
	Trichomoniasis	Finches	Lawson et al. (2012), Simpson et al. (2013)
	Papillomatosis	Chaffinch	Everest (unpubl. obs.)
Pheasant (*Phasianus colchicus*)	Salmonellosis		https://data.defra.gov.uk/Agriculture/APHA0190-Salmonella_Pheasants.csv
	Coccidiosis		Shuttleworth et al. (2015c)
	Cryptosporidiosis		Shuttleworth et al. (2015c)
	Rotavirus		Everest et al. (2009, 2011)
	Paramyxovirus		Brooks et al. (2014)
	Coronavirus		Cavanagh et al. (2002)
Hedgehog (*Erinaceus europaeus*)	Candida spp.		Simpson et al. (2011), Barlow et al. (2012)
	Herpes		Stack et al. (1990), Greenwood & Sanchez (2002)
	Leptospirosis		Greenwood & Sanchez (2002)
	Salmonellosis		Gaffuri (2012); Harker et al. (2013)
Brown rat (*Rattus norvegicus*)	Leptospirosis		Simpson et al. (2013)
	Cryptosporidiosis		Simpson et al. (2013)
	Neoplasia	Retroviruses	Stocking & Kozac (2008), Simpson et al. (2013)
	Cowpox		Obon et al. (2011), Himsworth et al. (2013)
	Toxoplasmosis	*T. Gondii*	Simpson et al. (2013)
	Lyme disease	*Borrelia* spp.	Millins et al. (2015)
Wood mouse (*Apodemus sylvaticus*)	Adenovirus		Greenwood & Sanchez (2002), Everest et al. (2012, 2013, 2014)
	Hantavirus		Greenwood & Sanchez (2002)
	Rotavirus		Greenwood & Sanchez (2002), Everest et al. (2009, 2011)
	Neoplasia	Retroviruses	Stocking & Kozac (2008), Simpson et al. (2013)
	Herpes		Greenwood & Sanchez (2002)
	Cowpox		Obon et al. (2011), Himsworth et al. (2013)
	Toxoplasmosis	*T. Gondii*	Simpson et al. (2013)
	Lyme disease, Leptospirosis.	*Borrelia* spp.	Millins et al. (2015)

Discussion

The development of more efficient, adaptive and humane methods of trapping is a shared aim amongst mammalogists (e.g. Genovesi and Bertolino, 2001; Powell and Proulx, 2003; Woodroffe et al., 2005; Schemnitz, 2009; Jung, 2016) and understanding the relative frequency of non-target captures is an important consideration (Iossa et al., 2007). To our knowledge there are no previously published non-target capture data from grey squirrel eradication attempts in the UK. In the two Italian grey squirrel control studies presented, we observed non-target captures as 3.42 and 10.87 captures per 100 trap days for the Piedmont and Liguria regions respectively, the latter figure elevated by a large black rat population. The level of non-target captures (4.32 non-target captures per 100 trap days) reported in the Anglesey eradication is broadly similar to the 3.35 figure recorded during the eradication of coypu (*Myocastor coypus*) from Britain (33,067 trap-nights, when 1,108 non-targets were caught) (Gosling et al., 1988).

During eradication it is important to catch and remove the bulk of the target species population rapidly (during the knock down phase) and then maintain intensive search effort to ensure that all residual animals are caught (Clout and Veitch, 2002). Trapping may encompass large geographical areas and, as was the case on Anglesey, balancing trap inspection frequency with maximising the number of traps that can be operated per day is often challenging. This time partitioning dilemma is exacerbated because a 'detect-then trap' approach, as often used in mink (*Mustela vision*) eradication (Oliver et al., 2016), is by logistics, less applicable to grey squirrels.

Mink live at low densities, range over large spatial areas but focus activity on linear riparian features, which aids detection. In contrast, grey squirrels have a relatively small home range area, can occupy a broad spectrum of wooded habitats across the landscape and thus, the network of dedicated sample points required to confidently detect low density regional presence would be so intense that it would be prohibitively expensive.

The Anglesey grey squirrel eradication took 16 years (see Shuttleworth et al., 2015b), and the available non-target data only covers a small proportion of this period. Hence, thousands of individuals, and a wide variety of woodland species, are therefore likely to have been caught within live-traps during the control programme. There are unfortunately no data on the reproductive state of these animals, the duration of their confinement, the presence or extent of any external injuries, damage to pelage, or the frequency of mortality within traps. There may also have been indirect impacts on dependent offspring and in some cases conspecifics. Krebs et al. (1981) for example, observed that the temporary removal (two or less hours) of a paired female great tit resulted in a greater vocalisation by the male, which may elevate his predation risk and further disrupt the breeding cycle.

Clear guidance on hopper design and positioning were made to reduce non-target species access to warfarin poison bait when used for grey squirrel control (Gurnell, 1996; Mayle et al., 2007) and regarding the diameter (60mm) of spring-trap tunnel entrances (Mayle et al., 2007). However, despite recent recommendations (Parrott et al., 2009; Sikes and Animal Care and Use Committee, 2016), grey squirrel control guidance typically only highlights a general need to 'avoid by-catch' or 'release non-target species when the trap is checked', (RSNE undated; Huxley, 2003; Mayle et al., 2007; BASC, Undated a, Undated b; Dutton, 2016). There is no description of the risks posed to captured animals or guidance on specific methods to minimise non-target captures.

Placing live-capture traps on tree mounted platforms would limit non-target captures of many mammalian species e.g. hedgehog, rabbit and red fox, but in many woodlands, particularly those with open public access, platform mounted traps are very visible, raising risk of vandalism, theft and release of grey squirrels. Narrowing the trap entrance, from 125 x 125mm to approx. 125mm x 60mm rectangles or, 60 x 60mm squares, would enable squirrels to enter, preclude larger animals such as pheasants, but would not prevent small birds from gaining access. The smaller the size of an animal, the more at risk it is at from hypothermia if trapped overnight. Closing the traps at night would reduce the risk, but may decrease the target trapping efficiency. Finally, selective baiting to target specific species can be effective (King et al., 2007).

Tree mounted modified Fineren boxes containing Magnum 116 traps may provide a practical solution to minimising by-catch in grey control operations, but only in woodlands where red squirrels and species such as the pine marten (*Martes martes*) are known to be absent. To the casual observer, these boxes look like bird boxes and they can be easily fixed directly onto a tree trunk. In addition, the entrance hole is not visible and any animal trapped inside is out of sight. The exclusion of non-targets including small passerine species during spring and summer trials is encouraging, particularly as these are smaller than the target species and addressing that scenario can be challenging.

The 65mm diameter entrance hole excludes larger birds (e.g. pheasants and corvids) and mammals (and reflects the broader findings of tunnel exclusion experiments of Short and Reynolds, 2001). However, more research is required to fully understand the true efficacy of Magnum 116 traps set in modified Fineren boxes relative to live-capture trap designs in order to make an informed assessment of their value in eradication programmes.

In addition to being both highly selective and yet accessible to grey squirrels, a spring-trap design must also be humane. In this study, a single animal was not killed quickly on capture as it was caught by a limb. The remaining individuals were caught by the head, neck, chest or midriff. In a previous and preliminary Magnum 166/Fineren box study, Shuttleworth et al. (2016a) observed 89% of (n=19) animals were found dead during box inspection. Combining those data with our recent findings presented here, indicates that 89/91 (98%) were dead on Magnum 116 trap inspection. There is therefore a choice if control is to be carried out: is it more acceptable for negative impacts to fall greatly upon a small proportion of the target species that are trapped but remain alive in kill-traps (c.2 per 100 grey squirrel captures in our north Wales study) and some non-target species also being killed by a spring-trap, or for the impacts (including mortality) associated with confinement in live-capture traps (Table 2) falling on all species (228 non-targets per 100 grey squirrel captures in north Wales)?

In the UK live-trap disinfection typically only occurs when a grey squirrel has been caught, and thus in many instances, different non-target species (including red squirrel) might have entered a trap sequentially with no disinfection having taken place between respective captures. There are no data on types, or relative rates of viral, or other infections amongst non-target animals, but there is a potential risk of inter-specific cross infection. The non-target species present within the 2010-2013 north Wales data set, are associated with a variety of potentially pathogenic infections, and trapping may directly affect the pattern of epidemiology across the species spectrum (Table 3). Although the presence of these pathogens, as a sub-clinical infection, would not normally be expected to be detrimental to the red squirrel, the presence of an underlying infection, or competition effects via habitat fragmentation, or competition for resources by sympatric grey squirrels, may result in the sub-clinical infection becoming a clinically-significant event. We recommend that trap disinfection should occur after all captures of both target and non-target species.

The grey squirrel has significant negative effects upon native forest fauna and ecosystems (Gurnell et al., 2016) and its eradication from landscapes such as Anglesey, offers clear long-term environmental benefits. The challenges and choices we make in how to undertake removal, and the corresponding level of risk to non-target species, are therefore illustrative of the need to ensure that additional invasive forest mammalian pests are not released into our natural environment.

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