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An assessment of animal welfare impacts in wild Norway rat (Rattus norvegicus) management

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Abstract

*Norway rats (*Rattus norvegicus*) are considered one of the most significant vertebrate pests globally, because of their impacts on human and animal health. There are legal and moral obligations to minimise the impacts of wildlife management on animal welfare, yet there are few data on the relative welfare impacts of rat trapping and baiting methods used in the UK with which to inform management decisions. Two stakeholder workshops were facilitated to assess the relative welfare impacts of six lethal rat management methods using a welfare assessment model. Fifteen stakeholders including experts in wildlife management, rodent management, rodent biology, animal welfare science, and veterinary science and medicine, participated. The greatest welfare impacts were associated with three baiting methods, anticoagulants, cholecalciferol and non-toxic cellulose baits (severe to extreme impact for days), and with capture on a glue trap (extreme for hours) with concussive killing (mild to moderate for seconds to minutes); these methods should be considered last resorts from a welfare perspective. Lower impacts were associated with cage trapping (moderate to severe for hours) with concussive killing (moderate for minutes). The impact of snap trapping was highly variable (no impact to extreme for seconds to minutes). Snap traps should be regulated and tested to identify those that cause rapid unconsciousness; such traps might represent the most welfare-friendly option assessed for killing rats. Our results can be used to integrate consideration of rat welfare alongside other factors, including cost, efficacy, safety, non-target animal welfare and public acceptability when selecting management methods. We also highlight ways of reducing welfare impacts and areas where more data are needed.*

Keywords: *animal welfare, commensal rodent, Norway rat, pest control, United Kingdom, wildlife management*

Introduction

Norway rats (*Rattus norvegicus*) are present throughout most of Europe, and in parts of North and South America, Australasia, Africa, Asia and on many islands (Lund 2015; Centre for Agriculture and Bioscience International [CABI] 2019). Their prodigious reproductive capacity, small size, omnivory, dietary opportunism, behavioural flexibility and agility make them one of the most significant and prolific urban pests in the world (Himsworth *et al* 2013; Buckle & Smith 2015).

Rats have devastating impacts on human and animal health, food, agriculture, property and the environment (Meerburg *et al* 2009; Battersby 2015; Lambert *et al* 2017). They are often killed in an effort to control populations and, in the UK, there is a legal obligation in some circumstances to control rats, under the Prevention of Damage by Pests Act (1949). UK local authorities respond to hundreds of thousands of requests to manage rats each year, more than any other vertebrate species (Baker *et al* 2020), with large numbers also managed by private pest control operators, farmers and householders. Total UK rat management is estimated to cost many £GBP millions annually (Jacob & Buckle 2018). Management primarily involves poisoning or trapping, the main priorities being safe (Campaign for Responsible Rodenticide Use [CRRU] UK 2021) and quick (Baker *et al* 2020) population control.

Wildlife management has the capacity to impact the welfare of targeted animals (Fisher *et al* 2010) but, historically, the welfare impacts of killing free-living vertebrates have received little attention from animal welfare scientists, legislators and the public (Littin & Mellor 2005). It is now increasingly recognised that where people adversely affect animal welfare they should minimise those impacts wherever possible (Littin *et al* 2004; Dubois *et al* 2017). Indeed, the perceived humaneness of management methods is a significant factor in the social acceptability of wildlife management (Littin & Mellor 2005; Špur *et al* 2016; Boulet *et al* 2021). In the UK, it is an offence under the Animal Welfare Act (2006) (Animal Health and Welfare [Scotland] Act 2006, Welfare of Animals Act [Northern Ireland] 2011) for a person to cause unnecessary suffering to a wild animal under their control, such as an animal caught in a trap (Natural England 2010). There is therefore in some cases a legal — and arguably, in all cases, a moral — imperative to minimise, where possible, welfare impacts in rat management and to strive continually to further reduce impacts.

Welfare concern has been particularly lacking for commensal rodents (Mason & Littin 2003). Rats are sentient animals, yet their treatment varies enormously with context (Fraser 2008), for example, whether they are laboratory animals, pets or wild rats (Berdoy & Drickamer 2007). Many millions (or potentially even billions [Fischer & Lamey 2018]) of rats and mice (*Mus musculus*; *Apodemus sylvaticus*) are estimated to be killed globally as pests every year (Mason & Littin 2003), often using methods that have worse welfare outcomes than are available for other species (Baker *et al* 2020). Indeed, in their review of the humaneness of rodent pest control, Mason and Littin (2003) identified "remarkable paradoxes in the way society treats different classes of animal." Concerns have been raised, in particular, about the welfare impacts of anticoagulant rodenticides, cholecalciferol rodenticide, snap traps and glue traps (Pesticides Safety Directorate [PSD] 1997; Mason & Littin 2003; Fisher *et al* 2010; Baker *et al* 2012; Fenwick 2014). Some rat management methods may also impact the welfare of non-target animals, for example, through primary or secondary poisoning, or by accidental trapping or injury caused by snap traps, cage traps or glue traps (Mason & Littin 2003; Nakayama *et al* 2019).

A key step towards more humane rodent management is for pest controllers to understand the welfare impacts of the methods at their disposal (Kraaijeveld-Smit 2015). However, little information is available on the relative welfare impacts of different rat management methods and, in order to minimise these impacts, it is first necessary to assess them as objectively as possible. To do this, we used a welfare assessment model ('the model'), devised by Australian scientists for assessing the relative humaneness of pest animal control methods (Sharp & Saunders 2011). This model has been used successfully for assessing welfare impacts on a range of species in Australia (Sharp & Saunders 2011), New Zealand (Fisher *et al* 2010) and the UK (Baker *et al* 2016).

The overall objective of this research was to assess the relative welfare impacts of six lethal rat management methods. The assessment included five methods commonly used in the UK (anticoagulant rodenticide [AR] poisoning, cholecalciferol [CCF] poisoning, snap trapping [ST], glue trapping [GT] and cage trapping [CT] — the latter two followed by a concussive blow to the head [CBH or concussive killing]) — and another, non-toxic cellulose (CELL) baiting. While the active ingredient in CELL, powdered corn cob, is approved under the EU Biocidal Products Regulation (2013), it is not currently authorised for use in the UK. However, this method is claimed to be safer environmentally than rodenticides (Mason & Littin 2003; Buckle & Eason 2015), so we included it in this study. Sub-objectives were to:

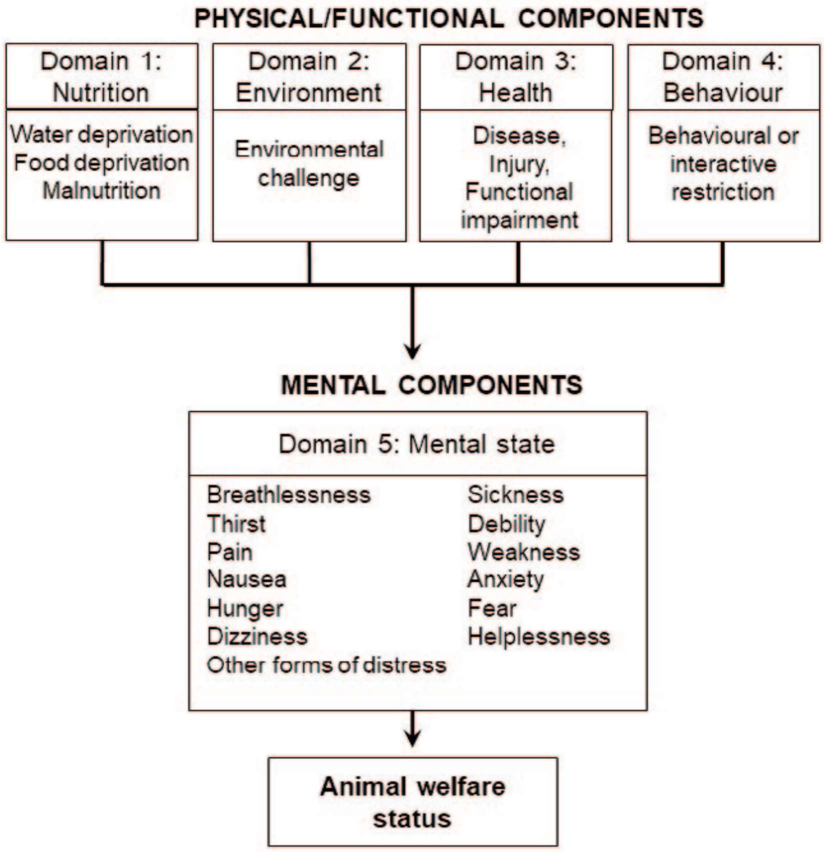
- Collate information on best practice rat management methods and potential associated welfare impacts;
- Draft standard operating procedures (SOPs) for six rat management methods;
- Identify, via stakeholder workshops, consensus scores for the relative welfare impact of each management method using the model;
- Compare the methods by welfare impact score for use in decision-making;
- Identify missing data needed to improve welfare assessments; and
- Suggest how welfare impacts might be reduced in rat management.

Materials and methods

Welfare assessment model

The model (Sharp & Saunders 2011) is a practical framework, designed to assess the relative welfare impact of a management method on a single animal, so that methods can be ranked according to their welfare impact scores. Assessments are made by a group of stakeholders using information from the literature and discussion to reach consensus. It is assumed that each method is applied according to a standard operating procedure (SOP), because procedural variation in the method may have considerable impact on welfare outcomes. The model comprises two parts. Part A examines the overall welfare impact of the

Figure 1



The welfare impact domains from the Five Domains Model. Adapted from Beausoleil and Mellor (2015b).

method, excluding any action that causes death. Impacts are considered under each of five welfare domains (four physical/functional domains: D1 nutrition, D2 environment, D3 health, D4 behaviour; and one mental domain: D5 mental state [see Figure 1]) based on Mellor and Reid's more general Five Domains Model (1994), which was developed from the UK Farm Animal Welfare Council's Five Freedoms (FAWC 2009). For each of D1–4, assessors identify an impact category (no impact, mild impact, moderate impact, severe impact or extreme impact), reflecting the intensity of impact, with reference to a set of Part A impact scales (Online Resource 1; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material; reproduced with the permission of Sharp and Saunders 2011). The impact in D5 represents mental experiences (eg anxiety/fear/pain arising from impacts in D1–4) and is often the maximum of those scores. That is, impact scores in D1–4 are based on observable/measurable indicators of impacts on the physical/functional state of the animal. These data are then used to cautiously infer the animal's likely mental/affective experiences, which cannot be evaluated directly, in D5 (Mellor & Beausoleil 2015).

Ultimately, an overall impact category is assigned; this is usually the score allocated in D5, but if the impact in D5 is unknown or cannot be established, the overall impact is represented by the highest score among D1–4. A category representing the duration of impact under Part A (immediate to seconds, minutes, hours, days, weeks) is also identified. Then, the impact intensity and duration are combined using a Part A scoring matrix (Figure 2) to assign an overall welfare impact score, ranging from 1 (no impact) to 8 (severe/extreme impacts over days/weeks) for Part A.

Part B of the model is applied only to lethal methods and examines the effects of the killing method only. The intensity of suffering (no suffering, mild suffering, moderate suffering, severe suffering, extreme suffering) is evaluated against a set of Part B impact scales (Online Resource 2; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material; and reproduced with the permission of Sharp and Saunders [2011]). The duration of suffering equates to the time from the first sign of impact to irreversible unconsciousness (immediate to seconds, minutes, hours, days, weeks). Finally, the intensity and duration of suffering are combined using a Part B scoring matrix (Figure 3) to assign a Part B score, ranging from A (no suffering) to H (severe/extreme suffering over days/weeks).

Figure 2

Overall impact on welfare	Duration of impact				
	Immediate to Seconds	Minutes	Hours	Days	Weeks
EXTREME	5	6	7	8	8
SEVERE	4	5	6	7	8
MODERATE	3	4	5	6	7
MILD	2	3	4	5	6
NO IMPACT	1	1	1	1	1

Part A Scoring matrix. Reproduced with permission of Sharp and Saunders (2011).

Figure 3

Level of suffering (after application of the method that causes death but before insensibility)	Time to insensibility (minus any lag time)				
	Immediate to Seconds	Minutes	Hours	Days	Weeks
EXTREME	E	F	G	H	H
SEVERE	D	E	F	G	H
MODERATE	C	D	E	F	G
MILD	B	C	D	E	F
NO IMPACT	A	A	A	A	A

Part B Scoring matrix. Reproduced with permission of Sharp and Saunders (2011).

Assessment outcomes are scored on a worksheet. In this study, when applying Part B of the model, impacts in each of D1–5 were discussed in turn before selection of an overall category for intensity of suffering. Also, stakeholders each nominated a confidence score, ranging between 0 and 3 (see scoring criteria in Table 1), to reflect their confidence in the overall impact and duration categories (Part A) and intensity of suffering and time to unconsciousness (Part B) allocated for each method.

Assessment materials

A Best Practice SOP was drafted by SEB for each of the six methods, including sections on Background, Application, Animal Welfare Considerations, Health and Safety Considerations, Equipment Required, Procedures and References (Online Resources 3–8; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Background reading material was collated from scientific papers and reports on known and potential welfare impacts of the six methods under assessment. Where data were sparse for Norway rats, information on other species, sometimes humans, was included. Information was either summarised for stakeholders or relevant parts of papers were highlighted for ease of reference.

Workshops

Fifteen candidate stakeholders were identified from among experts in wildlife management, rodent management, rodent biology, animal welfare science, and veterinary science and medicine. Stakeholders were drawn from known experts; they were based in the UK, Germany, New Zealand and Australia. Sharp and Saunders (2011) state that assessments using their model should be conducted by a panel of experts in animal welfare and behaviour and practical pest management; the fifteen participants here provided an appropriate balance of expertise, while allowing manageable workshop discussions with full participation. Stakeholders were emailed information about the project and invited to take part in two half-day online workshops (using Microsoft® Teams); they were not offered any financial incentive to take part. All agreed to participate and signed consent forms. Fourteen stakeholders subsequently joined SEB as co-authors on this paper. A few days before the first workshop, the six SOPs and background reading were circulated to stakeholders, together with a brief description of the model, the impact scales and scoring matrices. Stakeholders were asked to read these prior to beginning the workshops. Workshops took place on 1st and 16th December 2020. SEB chaired the workshops, outlined how the model is applied and facilitated the welfare assessments. Stakeholders briefly explained their relevant background at the beginning of the first workshop. A set of assumptions was agreed upon for each method before assessments took place (see Online Resources 10–18; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). For example, for GTs, the assumptions were that: best practice is followed in accordance with the relevant SOP; GTs are used indoors only; GTs are deployed and existing food sources are left undisturbed; and GTs are checked every 12 h. Stakeholders then discussed, assessed and scored each method in turn, the whole workshop process taking 9.5 h. The components of the methods assessed are detailed in the SOPs and summarised in Table 2. SOPs described deployment scenarios for the methods: STs were deployed unbaited (in boxes/tunnels), CTs were baited, GTs were simply deployed (placed uncovered and unbaited on a flat surface) and ARs, CCF and CELL were deployed in two alternative scenarios, either: (i) any bait boxes/tunnels or trays to be used were deployed (unbaited) a few days before beginning AR/CCF/CELL treatment; or (ii) AR/CCF/CELL baited boxes/tunnels or trays were deployed straight away. In both cases, existing food sources were removed wherever possible.

Table 1 Confidence scores applied.

Confidence score	Level of confidence
0	No animal data available, possible negative affective experiences inferred from human reports
1	Low confidence, more specific/detailed animal data required
2	Moderate confidence, more specific/detailed animal data would clarify
3	High confidence

Adapted from Beausoleil *et al* (2016).

Ethical approval

This article does not contain any studies with animals performed by any of the authors. All procedures involving human participants were approved by the University of Oxford's Medical Sciences Interdivisional Research Ethics Committee (reference R71195/RE001) and in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Results

The 15 stakeholders often had expertise in more than one area, but their primary fields were represented as follows: wildlife management (n = 2), rodent management (n = 4), rodent biology (n = 1), animal welfare science (n = 4), and veterinary science and medicine (n = 4). Details of the assessments, welfare impact scores and associated confidence scores are shown in Table 3. Overall welfare impact scores for Parts A and B are plotted in Figure 4 for ease of comparison among methods. Welfare impact scores did not distinguish between different deployment scenarios for traps/bait stations/tunnels or boxes associated with different methods (Table 3), and so scores for deployments were largely immaterial. STs produced no impacts to extreme impacts, causing unconsciousness either immediately or within seconds to minutes, scoring welfare impact scores of A–F. Capture by CT caused moderate to severe impacts for hours, scoring 5–6, while subsequent concussive killing of

Table 2 Components of the six rat management methods assessed.

Method	Part A: Deployment	Part A: Live capture	Part B: Killing
Snap traps	Unbaited snap traps in boxes‡		Snap trap capture
Cage traps and concussive blow to the head	Baited cage traps§	Cage trap capture	Rat moved to sack and concussive blow to the head
Glue traps and concussive blow to the head		Glue trap capture	Concussive blow to the head (on glue trap)
Anticoagulants (with Part A deployment scenario 1†)	Boxes‡ unbaited initially Anticoagulant bait added a few days later Existing food sources removed where possible		Anticoagulant poisoning
Anticoagulants (with Part A deployment scenario 2†)	Boxes‡ baited with anticoagulant straight away Existing food sources removed where possible		Anticoagulant poisoning
Cholecalciferol (with Part A deployment scenario 1†)	Boxes‡ unbaited initially Cholecalciferol bait added a few days later Existing food sources removed where possible		Cholecalciferol poisoning
Cholecalciferol (with Part A deployment scenario 2†)	Boxes‡ baited with cholecalciferol straight away Existing food sources removed where possible		Cholecalciferol poisoning
Cellulose (with Part A deployment scenario 1†)	Boxes‡ unbaited initially Cellulose bait added a few days later Existing food sources removed where possible		Cellulose ingestion
Cellulose (with Part A deployment scenario 2†)	Boxes‡ baited with cellulose straight away Existing food sources removed where possible		Cellulose ingestion

Blank cells are not relevant to assessment for a particular method; glue trap deployment was not deemed to impact upon rats until they are trapped, so deployment cell is blank for glue traps.
† In deployment scenario 1, for the three baiting methods, boxes/tunnels or trays are deployed (without bait) a few days in advance of beginning baiting treatment. In deployment scenario 2, anticoagulant/cholecalciferol/cellulose baited boxes/tunnels or trays are deployed straight away. Existing food sources are removed wherever possible in both scenarios.
‡ Box = box/tunnel used to protect anticoagulant, cholecalciferol or cellulose baits or snap traps from non-target animals, or tray used to present anticoagulant, cholecalciferol or cellulose baits in some indoor settings.
§ Untreated bait is used to attract rats into cage traps.

the rat in a sack produced moderate impacts for minutes, scoring D. Capture by GT had an extreme impact for hours, scoring 7, and concussive killing of the rat on the GT produced mild to moderate impacts, for seconds to minutes, scoring B–D. Killing with any of the bait treatments caused a severe to extreme impact for days, scoring G–H (Figure 4, Table 3). Stakeholder confidence scores for most assessments were high and there was low variability in confidence among stakeholders (Online Resource 9; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Details supporting assessment outcomes are provided below and more fully in assessment worksheets (Online Resources 10–18; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

Snap trapping

Deployment of STs (and boxes or tunnels) scored a welfare impact of '5' under Part A, based on a 'mild' impact lasting 'days.' This was due to a 'mild' behavioural impact in D4 because rats are likely to experience opposing drives to both avoid and explore novel objects (Ennaceur *et al* 2009), such as traps and boxes/tunnels. This would be expected to lead to 'mild' anxiety in D5. Part A impacts occur for several days before rats approach traps and may become trapped. Confidence in these scores was high, 3 (Table 3). Under Part B, STs scored 'A–F', because a trap taking up to 5 min to produce irreversible unconsciousness could cause suffering ranging from 'no' through to 'extreme' impact (confidence was low, 1) for between 'immediate/seconds' and 'minutes' (confidence was medium, 2). This range of scores was largely due to uncertainty around functional impacts (D3), which arose because of potential variation in trap strike location and power, and therefore injury type and mode of death. Ideally, the trap would strike the caudal part of the cranium or the upper cervical vertebrae with sufficient impact momentum to cause immediate or rapid unconsciousness followed by death (Mason & Littin 2003; Parrott *et al* 2009; Morriss & Warburton 2014). However, strikes elsewhere, or weaker strikes, could cause haemorrhaging, paralysis, asphyxiation or occlusion of blood flow to the brain. An animal losing substantial quantities of blood is likely to become unconscious before death as a result of a fall in blood pressure. Trapped animals may experience cardiogenic shock (due to heart failure) and haemorrhagic shock (Gregory 2004). The time to uncon-

Table 3 Welfare assessment results for the six rat management methods.

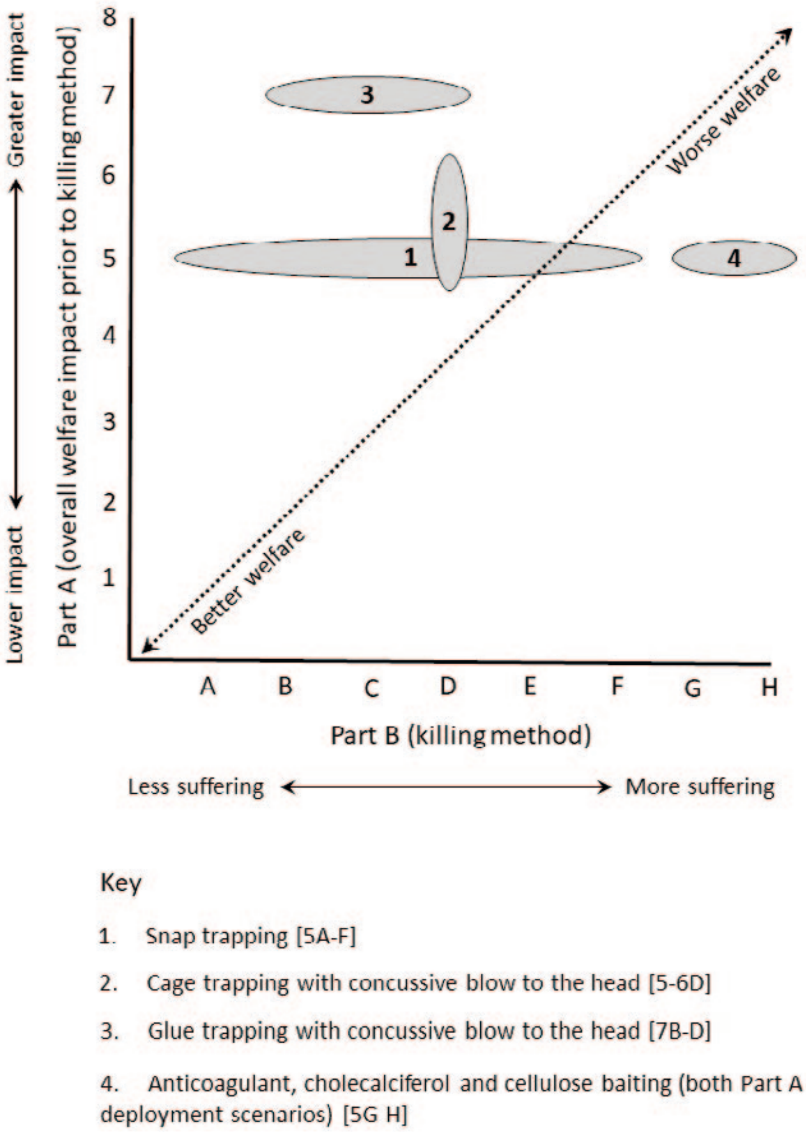
Method	Part A: Deployment			Part A: Live capture			Part B: Killing		
	Impact	**Duration**	**Welfare impact score**	**Impact**	**Duration**	**Welfare impact score**	**Impact**	**Duration**	**Welfare impact score**
Snap traps	Mild 3 (3) n = 15	Days 3 (2–3) n = 15	**5**				No–Extreme 1 (1–2) n = 13	Immediate/Seconds–Minutes 2 (1–3) n = 12	**A–F**
Cage traps with concussive blow to the head	Mild 3 (3) n = 15	Days 3 (3) n = 15	**5**	Moderate–Severe 2 (2–3) n = 14	Hours 3 (3) n = 15	**5–6**	Moderate 2 (1–3) n = 15	Minutes 3 (3) n = 15	**D**
Glue traps with concussive blow to the head				Extreme 3 (2–3) n = 15	Hours 3 (3) n = 15	**7**	Mild–Moderate 3 (2–3) n = 15	Seconds–Minutes 3 (3) n = 15	**B–D**
Anticoagulants (with Part A deployment scenario 1‡)	Mild 3 (2–3) n = 14	Days 3 (2–3) n = 14	**5**				Severe–Extreme 2 (2–3) n = 14	Days 3 (2–3) n = 14	**G–H**
Anticoagulants (with Part A deployment scenario 2‡)	Mild 3 (1–3) n = 15	Days 3 (3) n = 15	**5**				Severe–Extreme 2 (2–3) n = 14	Days 3 (2–3) n = 14	**G–H**
Cholecalciferol (with Part A deployment scenario 1‡)	Mild 3 (2–3) n = 14	Days 3 (2–3) n = 14	**5**				Severe–Extreme 3 (3) n = 14	Days 3 (2–3) n = 14	**G–H**
Cholecalciferol (with Part A deployment scenario 2‡)	Mild 3 (1–3) n = 15	Days 3 (3) n = 15	**5**				Severe–Extreme 3 (3) n = 14	Days 3 (2–3) n = 14	**G–H**
Cellulose (with Part A deployment scenario 1‡)	Mild 3 (2–3) n = 14	Days 3 (2–3) n = 14	**5**				Severe–Extreme 3 (2–3) n = 15	Days 3 (2–3) n = 15	**G–H**
Cellulose (with Part A deployment scenario 2‡)	Mild 3 (1–3) n = 15	Days 3 (3) n = 15	**5**				Severe–Extreme 3 (2–3) n = 15	Days 3 (2–3) n = 15	**G–H**

Welfare impact scores (shown in bold) are derived from Impact and Duration categories (shown in Impact and Duration columns) using scoring matrices (see Figures 2 and 3). Numbers in the Impact and Duration columns are median confidence score† (and confidence score range), while n = number of stakeholders contributing confidence scores; n was variable depending on the number of stakeholders present in the workshop at the time. Blank cells are not relevant to assessment for a particular method; glue trap deployment was not deemed to impact upon rats until they are trapped, so deployment cell is blank for glue traps.

† Confidence scores are: 0 = no animal data available, possible negative affective experiences inferred from human reports; 1 = low confidence, more specific/detailed animal data required; 2 = moderate confidence, more specific/detailed animal data would clarify; 3 = high confidence.

‡ In deployment scenario 1, for the three baiting methods, boxes/tunnels or trays are deployed (without bait) a few days in advance of beginning baiting treatment. In deployment scenario 2, anticoagulant/cholecalciferol/cellulose baited boxes/tunnels or trays are deployed straight away. Existing food sources are removed wherever possible in both scenarios.

Figure 4



Welfare impact scores for the six rat management methods. Assessments assumed that glue traps were checked within 12 h and cage traps were checked shortly after dawn and at dusk.

sciousness and time to death will both depend on the rate of blood loss and, where a body strike occurs, on whether there is any fatal compression of the heart and lungs, neurological damage, or other physical injury impairing core functions, such as respiration. A conscious trapped rat will experience behavioural impacts (D4) such as being unable to escape or socialise. Mental impacts (D5) include pain, fear and severe distress (Parrott *et al* 2009). Part B impacts occur for anywhere between 'immediate/seconds' and 'minutes' because the trap assessed is assumed to meet the International Agreement on Humane Trapping Standards (AIHTS) (see SOP in Online Resource 10; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). The overall score was 5A–F (Figure 4, Table 3).

Cage trapping followed by concussive killing

Deployment of CTs scored a Part A impact of '5', based on a 'mild' impact lasting 'days', for the same reasons as for STs (above); again, confidence in these scores was high. Capture in the cage trap itself scored a separate Part A impact of '5–6', based on a 'moderate' to 'severe' impact (medium confidence, 2) lasting 'hours' (high confidence, 3). This was largely due to a 'moderate' to 'severe' impact in D4, since normal behaviour and movement are restricted by the cage. Rats will be unable to forage, move or escape the attention of predators. Lactating females will be prevented from caring for young pups. Rats may experience 'mild' nutritional, environmental and functional impacts in D1–3, including water and possibly food restrictions, loss of bodyweight through dehydration (Pearson *et al* 2003), damp or thermal challenge, stress and injuries sustained when trying to escape. Trapped rats are likely to experience 'moderate' to 'severe' fear and distress (Mason & Littin 2003), producing mental impacts in D5. Rats may be trapped for up to 12 h before being found and killed, if best practice guidance is followed. Under Part B, the killing process (CBH) scored 'D', due to a 'moderate' impact (medium confidence, 2) lasting 'minutes' (high confidence, 3). This was largely due to behavioural impacts (D4) as a trapped rat is unable to escape the operator when they approach and then transfer the rat to a sack and position it for killing. Trapped rats will also experience fear and distress during this time (Mason & Littin 2003; Prout & King 2006), producing mental impacts (D5). Provided the CBH is administered effectively, the rat should be rendered unconscious instantly (American Veterinary Medical Association [AVMA] 2020) and there would be no functional impact in D3. The rat may experience mild environmental impacts (D2) when inside the sack. The whole killing process should take a few minutes at most. The overall score was 5–6D (Figure 4, Table 3).

Glue trapping followed by concussive killing

GTs were considered to have no impact until a rat made contact with a GT and became stuck to it. Capture on a GT scored '7' under Part A, based on an 'extreme' impact (high confidence, 3) lasting 'hours' (high confidence, 3). This was largely due to functional and behavioural impacts (D3, D4). Rats become more firmly stuck to the glue the more they struggle to escape, potentially tearing skin, breaking bones or chewing through their own limbs (Frantz & Padula 1983). Rats' eyes and mouths may become glued shut (Fenwick 2014). Rats become exhausted from struggling and may die of exhaustion or from suffocating in glue (Mason & Littin 2003). They may defaecate and urinate excessively (Ministry of Agriculture and Forestry [MAF] 2008) and become covered in faeces and urine (Frantz & Padula 1983). Trapped rats are unable to perform normal behaviours, such as foraging, moving, caring for pups or escaping from predators or from cannibalism by other trapped rats, and rats may self-mutilate if trapped for long periods (Mason & Littin 2003). Rats have a high metabolic rate and will experience nutritional impacts in D1. They will experience environmental impacts (D2) through being unable to thermoregulate effectively because they cannot move and because large areas of their skin may be covered with glue. Mental impacts (D5) are likely to include anxiety, fear, pain, hunger and thirst (Mason & Littin 2003), panic, distress (MAF 2008) and potentially breathlessness associated with suffocation. Rats may survive for hours on GTs (Fenwick 2014) and may be trapped for up to 12 h before being found and killed, if best practice guidance is followed. Under Part B, killing using CBH scored 'B–D', as a result of 'mild' to 'moderate' impacts (high confidence, 3) lasting between 'immediate to seconds' and 'minutes' (high confidence, 3). This was largely due to behavioural impacts (D4) because the rat is unable to escape as the operator approaches and kills it. Provided the CBH is administered effectively, the rat should be made instantly unconscious (AVMA 2020) and there should be no functional impact under D3. The rat will experience fear and distress during the killing process (Mason & Littin 2003), producing mental impacts (D5). The whole killing process should take only seconds to very few minutes. The overall score was 7B–D (Figure 4, Table 3). The Part B score here (B-D) is less than that for CBH applied after cage trapping (D) because CBH can be applied to a rat caught on a GT, while a rat in a CT will need to be moved to a sack before CBH can be applied.

Anticoagulant baiting

Separate Part A assessments were made for the two deployment scenarios for each of AR/CCF/CELL. The welfare impact score for box/tunnel or tray deployment under Part A was assessed as '5', based on a 'mild' impact (high confidence, 3) lasting 'days' (high confidence, 3), for both scenarios (1) and (2), for very similar reasons. This score resulted from nutritional and behavioural impacts, in D1 and D4. Nutritional impacts include reduced foraging success (because foraging trails [Galef & Buckley 1996] may be interrupted and key food sources may have been removed) and bait shyness towards treated baits for deployment procedure 2. Behavioural impacts include rats avoiding disturbed areas to begin with, increased foraging activity to compensate for disrupted foraging and opposing drives to avoid and explore novel objects (Ennaceur *et al* 2009). Observations indicate that rats take a few days to enter boxes or tunnels and eat (AR/CCF/CELL) bait when this is deployed.

Under Part B, AR baiting scored 'G–H', due to 'severe' to 'extreme' impacts (medium confidence, 2) lasting 'days' (high confidence, 3). Bleeding in the gut causes anorexia and weight loss (Fisher *et al* 2010), producing nutritional impacts (D1). Poisoned rodents sometimes remain above ground in exposed positions (Fisher *et al* 2010), potentially resulting in environmental impacts (D2). Functional impacts (D3) include haemorrhaging into muscles, joints (or articular cavities), the gastrointestinal tract, abdominal cavity or reproductive organs, causing severe impairment and ultimately death through anaemia or hypovolaemic shock (Fisher *et al* 2010). Bleeding into the lungs may compromise respiratory function (Fisher *et al* 2010). Haemorrhaging in the brain or central nervous system may cause ataxia or convulsions. Some rats are paralysed (Littin *et al* 2000). Poisoned animals exhibit poor overall condition (Mason & Littin 2003) and a hunched posture. Behavioural impacts (D4) include reduced grooming, struggling movements (Mason & Littin 2003), reduced home range sizes (Walther *et al* 2021) and reduced or altered activity (Cox & Smith 1992; Fisher *et al* 2010); rats become vulnerable to predation (Fisher *et al* 2010). Mental impacts (D5) include severe pain from internal bleeding (Pesticides Safety Directorate [PSD] 1997), breathlessness (Broom 1999; Beausoleil & Mellor 2015a), lethargy and weakness (Fisher *et al* 2010), thirst, dizziness, anxiety and fear. Rats typically remain conscious throughout anticoagulant poisoning until death (Mason & Littin 2003) and thus will remain capable of experiencing these symptoms from the

Table 4 Summary of knowledge gaps identified, which could be addressed with future research, and actions to reduce welfare impacts in rat management.

	Knowledge gaps	Actions to reduce welfare impacts
General		Improve training of pest control technicians
		Better inform the public on the need for good hygiene, proofing and environmental management
		Better enforce Food Safety and Health and Safety legislation
Snap traps	Prevalence of different welfare impacts experienced by rats in STs	Regulate STs or introduce a voluntary certification scheme with appropriate certification criteria
	Time taken by particular trap models to cause irreversible unconsciousness in rats	Position and set traps well, avoid contaminating traps with human scent, use an effective lure
		Use only STs that cause irreversible unconsciousness instantly or very rapidly, by striking the cranium or the upper cervical vertebrae with sufficient impact momentum
		Avoid STs with a small opening-angle and a jaw-type spring
Cage traps and concussive blow to head	Prevalence of different behavioural and interactive restrictions experienced by rats in CTs	Minimise the time rats spend in a CT, by checking traps more often or using remote monitoring devices
	Welfare impacts experienced by rats being transferred from CTs to sacks and undergoing CBH	Use covered rather than mesh traps. Provide water and bedding in CTs
		Improve training on using concussive killing
Glue traps and concussive blow to head	Welfare impacts experienced by rats undergoing CBH on GTs	Minimise the time rats spend on a GT, by checking traps more often or using remote monitoring devices
		Improve training on using concussive killing
Anticoagulants		Develop rodenticides with analgesics, sedatives or general anaesthetics
Cholecalciferol		Develop rodenticides with analgesics, sedatives or general anaesthetics
Cellulose	Not applicable as not suitable for practical use	Not applicable as not suitable for practical use

onset of signs to the time of death, a period lasting multiple days. The range of Part B scores reflects variation in the location of haemorrhaging and the speed of blood loss and thus loss of consciousness. The overall score was 5G–H (Figure 4, Table 3).

Cholecalciferol baiting

Part A assessments for the two alternative bait box or tray deployment procedures for CCF were as for ARs (see previously), both scoring '5', due to a 'mild impact' (high confidence, 3) lasting 'days' (high confidence, 3). Under Part B, CCF baiting scored 'G–H', due to 'severe' to 'extreme' impacts (high confidence, 3) lasting for 'days' (high confidence, 3). Nutritional impacts (D1) of CCF include anorexia (European Union [EU] 2020), weight loss, starvation and/or dehydration (Mason & Littin 2003). Environmental impacts (D2) are caused by behavioural changes, exposing rats to conditions outside their normal range. CCF causes functional impacts (D3) by interfering with calcium homeostasis, mobilising calcium from bones and increasing uptake in the gut, producing hypercalcaemia and calcification within organs including the kidneys, heart and blood vessels (Mason & Littin 2003). The cause of death is commonly acute heart or renal failure (Mason & Littin 2003; Rodenticide Resistance Action Group [RRAG] 2018). Osteomalacia (due to bone resorption) (RRAG 2018), vomiting, abnormal breathing, haemorrhaging, tremors and coma may all occur (Jolly *et al* 1993; PSD 1997; Mason & Littin 2003). Elevated circulating urea levels, secondary to renal failure, may cause cerebral disturbance and ataxia. Rats will exhibit poor condition, piloerection and a hunched posture (Mason & Littin 2003). Behavioural impacts (D4) include rats losing their normal reactions to external stimuli, compromising their ability to forage and escape predators (Mason & Littin 2003). Mental impacts, in D5, include sickness, lethargy, weakness, listlessness, pain, breathlessness (Jolly *et al* 1993; Mason & Littin 2003; Beausoleil & Mellor 2015a) and thirst. Animals may experience anxiety and fear because they are unable to escape or defend themselves normally. Pain and nausea are also likely when renal failure causes circulating urea levels in the blood to rise and because of build-up of urea crystals in organs and joints. Bone pain and muscle weakness may occur as a result of osteomalacia. Cholecalciferol poisoned humans may experience confusion, depression and fatigue as direct effects of hypercalcaemia on the nervous system. There is no evidence that consciousness is reduced before death (Fisher *et al* 2010), so rats probably remain capable of experiencing these symptoms from the onset of poisoning until shortly before the time of death. Signs are apparent for several days. The overall score was 5G–H (Figure 4, Table 3).

Non-toxic cellulose baiting

Part A assessments for the two alternative bait box or tray deployment procedures for CELL were as for ARs (see previously), both scoring '5' (high confidence, 3, for both impact and duration). Under Part B, CELL baiting scored 'G–H', due to 'severe' to 'extreme' impacts (high confidence, 3) lasting for 'days' (high confidence, 3). Rats primarily ingesting CELL experience starvation (Schmolz 2010), and dehydration, as water is drawn from the bloodstream into the gut lumen. Water intake declines, probably due to gut impaction, indicating interference with the normal physiological feedback mechanism (RRAG 2018). Rats may die as a result of these nutritional (D1) impacts. In Domain 2, rats may not seek shelter. Multiple functional impacts (D3) include dehydration (as fluid moves into the intestinal CELL bait), hypovolaemia, reduced blood pressure, tissue ischaemia, multi-organ failure and circulatory shock leading to death (RRAG 2018). Swollen CELL bait potentially causes gut obstruction; severe caecal obstruction is likely (Zhelev *et al* 2013). Rats are huddled and lethargic (Mason & Littin 2003). Behavioural impacts (D4) could include cannibalism, seen in captive rats (Hsieh *et al* 2017) and house mice (*M. musculus*) (Schmolz 2010; Hsieh *et al* 2017), and potentially driven by hunger or thirst, but this may not occur in free-ranging populations (Schmolz 2010). Mental impacts, in D5, include gastrointestinal pain and discomfort from gut distension, nausea or sickness, weakness due to hypovolaemia and likely hunger due to energy deprivation (Mason & Littin 2003). Ischaemic pain and dizziness may also arise due to inadequate tissue perfusion as hypovolaemia becomes pronounced. It is not known whether rats are thirsty as, despite being dehydrated, drinking is reduced even when water is available, probably due to interference with feedback mechanisms (RRAG 2018). Animals may experience anxiety and fear because they are unable to escape or defend themselves normally. Signs are likely to be apparent for several days (Schmolz 2010). The overall score was 5G-H (Figure 4, Table 3).

Discussion

There are both legal (Natural England 2010) and moral obligations (Littin *et al* 2004) to mitigate, where possible, welfare impacts in rat management. Management should be applied such that animal suffering is minimised (Dubois *et al* 2017) and efforts should be made continually to improve rat welfare through the development of better management methods, products and procedures. We assessed six lethal rat management methods, all of which scored welfare impacts under both parts of the model; stakeholder confidence in most scores was high. Welfare impact scores were relatively high for the three baiting methods (anticoagulants, cholecalciferol and cellulose) and for glue trapping with concussive killing. Anticoagulants and glue traps in particular are used to kill vast numbers of rats each year and welfare is likely to be poor for rats killed using these methods. If welfare impacts are a function of the degree to which an individual animal suffers, multiplied by the number of individuals affected, then rodent control using these methods must be among the most significant of deliberate human activities affecting animal welfare. Methods of rat management with substantial welfare impacts have been accepted probably because rat populations can erupt quickly, control is considered essential for protecting human and animal health (Meerburg *et al* 2009; Battersby 2015; Colombe *et al* 2019) and rats are often extremely unpopular with the public (Baker *et al* 2020). Also, rats killed using baiting methods often die out of sight and are rarely seen by the public.

While snap trapping, and cage trapping followed by concussive killing, both scored lower welfare impacts (better welfare outcomes) than baiting methods and glue trapping, it is not possible simply to rank the six methods by overall welfare impact score, because some scored higher for the non-lethal (Part A) components, and some for the lethal (Part B) components, of control, and Part A and Part B scores are not directly comparable (eg 5 does not equal E) (Sharp & Saunders 2011). However, some general conclusions can be drawn: deployment of traps/bait stations/tunnels or boxes was largely immaterial as this did not differentiate among methods; snap trapping can range from having no impact through to extreme impacts lasting seconds or minutes; capture by cage trap can have moderate to severe impacts lasting hours while subsequent concussive killing can have a moderate impact for minutes; capture by glue trap can have an extreme impact lasting hours while subsequent concussive killing can have a mild to moderate impact for seconds to minutes; killing with any of the baits can have severe to extreme impacts lasting for days. Below, we explore aspects of each method in turn, its welfare impact score and associated confidence scores, where confidence scores were not high, to determine how welfare impacts might be reduced and to identify missing data that should be collected to improve welfare assessments in future, either by defining more precisely the limits of welfare impacts or by increasing confidence in the scores allocated. Ways of reducing welfare impacts and missing data are summarised in Table 4.

Snap trapping

Snap traps are exempt from regulation in the UK and to our knowledge elsewhere, except Sweden. Almost no data exist on the welfare impacts produced by snap traps, or on how quickly they render rats unconscious (an exception being Morriss and Warburton [2014]), but these are likely to vary widely among snap trap types because their mechanical performance varies widely (Baker *et al* 2012). Welfare impacts will also depend on how skilfully traps are set and how the rodent approaches the trap. The Part A score (5) reflects days of mildly disrupted behaviour around traps, resulting in mild anxiety, before rats become trapped. Our assessment here assumed that snap traps met the current AIHTS criteria (ie causing irreversible unconsciousness within 5 min in ≥ 80% of 12 tests; Defra 2009), which apply to regulated spring traps in the UK (spring traps, excluding snap traps and mole traps), to mimic a situation in which the UK exemption from approval for snap traps is removed. Even under this scenario (an improvement on the current situation), there was still enormous uncertainty about the impacts of the lethal phase, with snap traps receiving a Part B score of A–F.

This A–F score reflects suffering ranging between no impact and extreme impact for up to minutes before rats become irreversibly unconscious in the trap. Stakeholders' confidence was only low (1) for the level of suffering and medium (2) for the duration of Part B suffering rats experienced in a snap trap. Thus, data are needed on welfare impacts experienced by snap-trapped rats (data on the percentage of snap-trapped rats killed with a particular model of trap that experience a fractured cranium or upper cervical vertebrae, paralysis, occlusion of blood vessels supplying the brain, acute haemorrhage or asphyxiation [Baker *et al* 2015], before losing consciousness), alongside time to irreversible unconsciousness. Welfare impacts could be minimised by using only snap traps that cause irreversible unconsciousness instantly or very rapidly, by striking the cranium or the upper cervical vertebrae with sufficient impact momentum (Parrott *et al* 2009). Such snap traps would effectively cause 'no impact' under Part B (score of A, 5A overall). One snap trap, the Smart Catch trap (Anticimex GmbH & Co KG; https://www.anticimex.com.sg/our-products/smart-catch), tested under the German Infection Protection Act scheme, causes irreversible unconsciousness in Norway rats within 30 s (mean 12 s; German Environment Agency [GEA] 2021) and could potentially approach this 'no impact' score. Morriss and Warburton (2014) tested and modified a snap trap, the Victor® Easy Set® Rat Trap, such that following modification, and when used in a horizontal set, it caused irreversible unconsciousness in ten out of ten black rats (*Rattus rattus)* within 46 s (mean 35 s); it should be noted though that black rats tend to be substantially smaller than Norway rats (Macdonald & Barrett 1993).

Snap traps should be regulated, as are other spring traps in the UK. However, our study shows that, even if snap traps met the approval standard currently applied to other spring traps in the UK (and aligned with the AIHTS), ie that 80% of 12 traps should cause irreversible unconsciousness within 5 min, then welfare outcomes for trapped rats (and likely mice) could still be very poor. Appropriate criteria should therefore be devised for snap traps (see, for example, those suggested by Schlötelburg *et al* 2021, which require traps to render rats [or mice] unconscious within seconds). In the absence of proper regulation, a voluntary snap trap certification scheme (an idea proposed by Baker *et al* 2017) could identify and promote good quality snap traps and drive continuous improvement of traps (Talling & Inglis 2009), by requiring traps not only to render rats unconscious within seconds, but also by categorising traps on the basis of their ability to meet various category standards (see the system devised by the NoCheRo Working Group; Schlötelburg *et al* 2021). The welfare impact of various snap traps should then be reassessed using the model; the Part B score might be more precisely defined, and significantly reduced, potentially making good quality snap traps the least inhumane option assessed for killing rats. Snap traps should then only be used if they meet the standard outlined in the NoCheRo guidance, or an equally rigorous welfare testing scheme. Until this can be achieved, snap traps with a small opening angle and jaw-type spring should be avoided because they generally have a lower impact momentum than other designs (Baker *et al* 2012). Traps with a wider opening angle and a double-peg spring generally have a greater impact momentum, although this cannot guarantee an effective body strike location or a low welfare impact (Baker *et al* 2012). Impacts prior to rats being trapped could be minimised by good positioning and setting of traps, avoiding contaminating traps with human scent and using an effective lure.

Cage trapping followed by concussive killing

Cage trapping followed by concussive killing scored 5 for deployment and 5–6D for capture and killing. The Part A deployment score (5) reflects days of unsettled behaviour around cage traps before capture, while the Part A capture score (5–6) relates to hours of moderate to severe impacts when rats are live trapped. (While this assessment assumed that traps were checked every 12 h, it is worth noting that many cage traps may be checked every 24 h, or even less frequently, meaning that rats would spend longer in traps). Stakeholder confidence was only medium (2) for this moderate to severe impact rating, indicating that more data are needed on the behavioural and interactive restrictions on cage-trapped rats. Impacts could be reduced by decreasing the time rats spend in a trap, by checking traps more often or using remote monitoring devices to alert operators to captures (Mason & Littin 2003). There are commercially available, and widely adopted technologies for electronic monitoring (eg https://zip.org.nz/products-list/2019/9/outpost), but it is not yet known at what scale such technologies might be feasibly deployed given their costs. Providing water and bedding in traps should decrease dehydration and chilling, and using covered rather than mesh traps might reduce cage-trap deaths (Dizney *et al*

2008). Releasing live-trapped rodents into unfamiliar areas is likely to have serious welfare implications (Bright & Morris 1994; Kenward & Hodder 1998) and thus killing trapped rats quickly with a low impact method may be better for their welfare overall.

The score for concussive killing, following cage trapping (D), reflects a moderate impact lasting minutes before irreversible unconsciousness occurs; this includes the period during which the operator approaches the caged animal which is likely to provoke fear and anxiety. This score is slightly higher than for concussive killing following glue trapping (B–D), because transferring a rat from the trap to a sack takes longer and application of the lethal blow may be less accurate when targeting a rat in a sack. The stakeholders' confidence in the moderate score was medium (2), indicating that more data are needed on the welfare impacts of transferring rats to sacks and killing them using concussion. Alternative killing methods which might have a lower welfare impact include inhalation anaesthesia (followed by cervical dislocation) or shooting with an air pistol, both applied in the trap. However, anaesthesia would probably be impractical due to health and safety, and environmental, requirements, and drugs will be prescription-only, severely limiting their use. Shooting is unlikely to be practical in commensal rodent control for safety reasons and the British Pest Control Association (BPCA 2018) states that all other control methods must be considered and documented before killing rats using an air gun. Reducing the welfare impact of killing cage-trapped rats might be most realistically achieved through improved training on using concussive killing, including using a sensitively made training video.

Glue trapping followed by concussive killing

Glue traps are banned on welfare grounds in the Republic of Ireland, New Zealand and India and their use is prohibited or restricted in some Australian states. In the UK, the Pest Management Alliance (PMA 2017) advises that professional rodent managers should use glue traps only when other methods have been ruled out or in high-risk environments when rats need to be removed immediately, eg on an aeroplane. Few data exist on the welfare impacts of glue traps (Fenwick 2014), but stakeholders' confidence in their assessment of this method was high (3). Capture on a glue trap followed by concussive killing scored 7B–D. The Part A score for capture (7) relates to hours of moderate to extreme impacts when rats are trapped in glue. The only way to reduce these impacts is to minimise the time for which rats are trapped. This might be achieved by checking traps more often or by using remote surveillance to monitor captures and killing captured rats immediately. (While this assessment assumed that traps were checked every 12 h, it is worth noting that many glue traps may be checked less frequently, meaning that rats would spend longer on traps). However, regular disturbance would likely reduce capture rates, while remote monitoring could be prohibitively costly. Such a labour-intensive method might be workable if glue trap use was truly exceptional, in which case the severity of a rat problem might justify the cost. However, glue traps are currently widely used in large numbers, in the UK, in circumstances where clients may not be prepared to pay for intensive monitoring. The Part B score (B–D) reflects mild to moderate impacts lasting up to minutes when the operator approaches and kills the rat using CBH, with the rat attached to the trap. As for cage trapping, the best way to reduce welfare impacts in killing glue-trapped rats would probably be through better training in applying concussive killing.

Baiting methods (anticoagulants, cholecalciferol and cellulose)

Rodent control relies heavily on anticoagulant rodenticides (Buckle & Smith 2015). UK legislation currently reflects EU regulation and most anticoagulants fulfil EU exclusion criteria for biocides (eg being persistent, bio-accumulative or toxic), meaning their use should not ordinarily be allowed. Nevertheless, in 2017, EU approval for anticoagulants was renewed on grounds that sufficiently effective alternatives for rodent control were limited. Further, cholecalciferol meets EU exclusion criteria, because it has endocrine disrupting properties, but the active ingredient is approved in the EU because it is considered valuable for controlling rats where anticoagulant resistance occurs, as well as presenting lower risks to human and animal health (European Commission [EC] 2019). Cellulose has been promoted as an environment-friendly, and non-target-friendly alternative to anticoagulants, but while its active ingredient is approved in the EU, no products containing cellulose itself are authorised for use.

A UK government review found all anticoagulants and cholecalciferol to be 'markedly inhumane' (PSD 1997), while all three baiting methods assessed here scored high welfare impacts (5G–H) (poor welfare outcomes) in this study and anticoagulants can also cause primary poisoning of non-target wild mammals, birds and reptiles, and secondary non-target poisoning of carnivores, raptors and owls (Nakayama *et al* 2019). The Part A score (5), for the three baiting methods, related to days of mildly disturbed behaviour around boxes/tunnels before rats enter these and ingest baits; the outcome was similar regardless of the deployment scenario used. The Part B score (G–H) reflects severe to extreme welfare impacts, lasting days, until loss of consciousness and death occur, although the specific nature of these impacts varied widely among the three baiting methods. In addition, rats affected sub-lethally by anticoagulant or cholecalciferol poisoning may experience long-term effects (Mason & Littin 2003).

While anticoagulants, cholecalciferol and cellulose scored identical welfare impact scores, the impacts of these methods are unlikely to be identical, because the type of suffering and the duration categories from which scores are derived contain considerable leeway. For example, the multiple likely qualities of unpleasant experience associated with cholecalciferol, and their likely severities, may mean the impact of cholecalciferol is greater than that of anticoagulants and cellulose, but this is not detected by the model,

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which allocates broad categories of welfare impact. While stakeholders' confidence was high (3) for all other aspects of the baiting assessments, it was only medium (2) for the level of suffering caused by anticoagulants. Studies involving administration of analgesic and anxiolytic drugs might clarify rats' experiences of pain and anxiety/fear following anticoagulant poisoning, as suggested by Fisher *et al* (2010). For example, a small study indicated that providing anticoagulant-treated rats with meloxicam (a non-steroidal anti-inflammatory analgesic) decreased the indicators of pain expressed by rats and therefore benefitted the welfare of anticoagulant-treated rats (FERA 2011).

Earlier suggestions that cellulose caused signs of pain for a few hours (Mason & Littin 2003) are rejected by the research undertaken in this study, which indicates that suffering lasts for days. Also, cellulose has low palatability (Schmolz 2010) and while this was improved with attractants in captive black rats (Zhelev *et al* 2013), cellulose is probably not suitable for practical use (Schmolz 2010). Aside from developing poisons with a lower welfare impact, one possibility for reducing the welfare impacts of anticoagulants and cholecalciferol may be to combine these with analgesics or compounds that reduce pain or cause sedation or unconsciousness (Mason & Littin 2003).

Alternative rat management methods

Other rat-killing methods available in the UK include phosphine gas, Goodnature® concussive traps and electrocution traps. Phosphine gas produces severe pain for hours to days (PSD 1997), but for safety reasons in the UK cannot be used indoors, or within 10 m of an occupied building, so it is unsuitable for many rat control situations. Goodnature® A24 rat traps, which kill by concussion, using a captive bolt, are approved in the UK; in trials with ten black rats they produced irreversible unconsciousness in a mean of 22.3 s (range: 15–29 s; Jansen 2011), but a recent study (in which the only Norway rat triggering an A24 rat trap received a non-lethal injury) suggests that more research may be required on their humaneness and efficacy with Norway rats (Ryan 2021). Electrocution traps may be relatively humane if they kill quickly (within seconds to minutes) but few data exist on the duration or type of impacts experienced by electrocuted rats (Mason & Littin 2003). Rat-killing methods not available in the UK include the acute poisons, zinc phosphide, cyanide and 1080. These may be more humane than the baiting methods assessed here (Mason & Littin 2003; Fisher *et al* 2010), but because they take effect quickly, they are extremely dangerous, and no antidotes are available for zinc phosphide or 1080. Fertility control is a possible non-lethal alternative, newly available for rats in the USA (but not currently available in the EU or UK), in the form of ContraPest® (Pyzyna *et al* 2018). ContraPest® is presented as a liquid feed and contains the active ingredients 4-vinylcyclohexene diepoxide (VCD) and triptolide. This could prove a useful rat management tool, although it would be a long-term option, rather than a quick solution (Croft *et al* 2021) and no data are available yet on its welfare impacts. Fertility control is widely promoted as humane, but it will bring its own impacts, potentially, for example, on behaviour, aggression, sociality, appetite, although these effects have not yet been studied. Environmental methods of managing rats, once a population is established, such as removing food, nesting material, water and cover may be seen as benign but could have very significant impacts on rat welfare, for example, causing them to starve or pups to be abandoned. We recommend that further research is conducted to assess these impacts.

Animal welfare implications

Rats are probably the most intensively managed wild mammal species in the UK. Given our findings, and the dependency of management on lethal methods, especially anticoagulants, rat management may represent the greatest anthropogenic impact on wild animal welfare. The most obvious way to reduce impacts on rat welfare is to prevent population establishment, eg by proofing and removing harbourage before rats are present, and to kill rats only where needed (Dubois *et al* 2017). Once established, there is currently no entirely humane way of removing rats. Where lethal management is necessary, and where practical, impacts could be minimised by prioritising use of good quality snap traps, and then cage traps with effectively applied concussive killing before considering anticoagulants, cholecalciferol or glue traps with concussive killing. Impacts might be further reduced by checking traps more frequently or using remote sensing to monitor traps, using covered cage traps with bedding, food and water, improving training in concussive killing or developing rodenticides combining anticoagulants or cholecalciferol with analgesics, sedatives or general anaesthetics. More data are needed on time to unconsciousness in snap traps, as well as the prevalence of different welfare impacts experienced by rats trapped in snap traps and cage traps and those being transferred from cage traps to sacks and undergoing concussive killing. Repealing the exemption of snap traps from regulation, and introducing better trap standards, in the UK, and introducing regulation elsewhere, or initiating a snap trap certification scheme (Schlötelburg *et al* 2021), would assist in identifying additional good quality snap traps and could provide the welfare data needed on those methods. Improving training of pest control technicians would have positive impacts on animal welfare and on reducing the spread of anti-coagulant resistance. The public must be better informed on the need for good hygiene, proofing and environmental management. Better enforcement of Food Safety and Health and Safety legislation would help enormously in modifying human practices.

Our results can be used to facilitate consideration of rat welfare in rat management, alongside other factors, such as cost, efficacy, safety, non-target welfare and public acceptability. Cost is likely to be a key factor in decision-making about rat management and research is required on balancing welfare with the costs of rat management methods. Meanwhile, our findings can complement two existing frameworks. The Risk Hierarchy proposed by the Campaign for Responsible Rodenticide Use (CRRU UK 2021) provides step-wise measures for preventing or removing a rat population. It emphasises proofing measures and removal of harbourage, and when lethal management is necessary, using the least severe method that is considered effective, as well as minimising non-target and environmental risks. Our results on the relative welfare impacts of methods could be incorporated or used alongside to assist in method selection. Dubois and colleagues' (2017) principles for ethical wildlife control emphasise, among other considerations, the importance of preventing problems and choosing the lowest welfare impact method, which for rats can now be informed by our findings.

Declaration of interest

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References

AVMA (American Veterinary Medical Association) 2020 *AVMA Guidelines for the Euthanasia of Animals.* AVMA: Shaumberg, IL, USA

Baker SE, Ellwood SA, Tagarielli, VL and Macdonald DW 2012 Mechanical performance of rat, mouse and mole spring traps, and possible implications for welfare performance. *PLoS ONE 7*: e39334. https://doi.org/10.1371/journal.pone.0039334

Baker SE, Macdonald DW and Ellwood SA 2017 Double standards in spring trap welfare: ending inequality for rats (Rodentia: Muridae), mice (Rodentia: Muridae) and moles (Insectivora: Talpidae) in the United Kingdom. In: Davies MP, Pfeiffer C and Robinson WH (eds) *Proceedings of the Ninth International Conference on Urban Pests* pp 139-145. Birmingham, UK

Baker SE, Maw SA, Johnson PJ and Macdonald DM 2020 Not in my backyard: public perceptions of wildlife and 'pest control' in and around UK homes, and local authority 'pest control'. *Animals 10*: 222. https://doi.org/10.3390/ani10020222

Baker SE, Sharp TM and Macdonald DW 2016 Assessing animal welfare impacts in the management of European rabbits (*Oryctolagus cuniculus*), European moles (*Talpa europaea*) and carrion crows (*Corvus corone*). *PLoS One 1*: e0146298. https://doi.org/10.1371/journal.pone.0146298

Baker SE, Shaw RF, Atkinson RPD, West P and Macdonald DW 2015 Potential welfare impacts of kill-trapping European moles *(Talpa europaea)* using scissor traps and Duffus traps: a post-mortem examination study. *Animal Welfare 24*: 1-14. https://doi.org/10.7120/09627286.24.1.001

Battersby SA 2015 Rodents as carriers of disease. In: Buckle AP and Smith RH (eds) *Rodent Pests and their Control* pp 81-100. CABI International: Wallingford, UK. https://doi.org/10.1079/9781845938178.0081

Beausoleil NJ, Fisher P, Littin KE, Warburton B, Mellor DJ, Dalefield RR and Cowan P 2016 A systematic approach to evaluating and ranking the relative animal welfare impacts of wildlife control methods: poisons used for lethal control of brushtail possums (*Trichosurus vulpecula*) in New Zealand. *Wildlife Research 43*: 553-565. https://doi.org/10.1071/WR16041

Beausoleil NJ and Mellor DJ 2015a Introducing breathlessness as a significant animal welfare issue. *New Zealand Veterinary Journal 63*: 44-51. https://doi.org/10.1080/00480169.2014.940410

Beausoleil NJ and Mellor DJ 2015b Advantages and limitations of the Five Domains model for assessing welfare impacts associated with vertebrate pest control. *New Zealand Veterinary Journal 63*: 37-43. https://doi.org/10.1080/00480169.2014.956832

Berdoy M and Drickamer LC 2007 Comparative social organization and life history of *Rattus* and *Mus*. In: Wolff JO and Sherman PW (eds) *Rodent Societies: an Ecological and Evolutionary Perspective* pp 380-392. University of Chicago Press: Chicago, USA

Boulet M, Borg K, Faulkner N and Smith L 2021 Evenly split: Exploring the highly polarized public response to the use of lethal methods to manage overabundant native wildlife in Australia. *Journal for Nature Conservation (Jena) 61*: 125995. https://doi.org/10.1016/j.jnc.2021.125995

BPCA (British Pest Control Association) 2018 *The Use of Air Guns in Pest Control; Code of Best Practice, First Edition*. British Pest Control Association: UK

Bright PW and Morris PA 1994 Animal translocation for conservation – performance of dormice in relation to release methods, origin and season. *Journal of Applied Ecology 31*: 699-708. https://doi.org/10.2307/2404160

Broom DM 1999 The welfare of vertebrate pests in relation to their management. In: Cowan DP and Feare CJ (eds) *Advances in Vertebrate Pest Management* pp 309-329. Filander Verlag: Furth, Germany

Buckle AP and Eason CT 2015 Control methods: Chemical. In: Buckle AP and Smith RH (eds) *Rodent Pests and their Control* pp 123-154. CAB International: Wallingford, UK. https://doi.org/10.1079/9781845938178.0123

Buckle AP and Smith RH 2015 *Rodent Pests and their Control*. CAB International: Wallingford, UK. https://doi.org/10.1079/9781845938178.0000

CABI (Centre for Agriculture and Bioscience International) 2019 *Invasive Species Compendium*. www.cabi.org/isc/datasheet/46829

Colombe S, Jancloes M, Riviere A and Bertherat E 2019 A new approach to rodent control to better protect human health: first international meeting of experts under the auspices of WHO and the Pan American Health Organization. *Weekly Epidemiological Record 17*: 197-203

Cox P and Smith RH 1992 Rodenticide ecotoxicology: prelethal effects of anti-coagulants on rat behaviour. *Proceedings of the Fifteenth Vertebrate Pest Conference* p 86. 1992, University of Nebraska, Lincoln, USA

Croft S, Aegerter JN, Beatham S, Coats J and Massei G 2021 A spatially explicit population model to compare management using culling and fertility control to reduce numbers of grey squirrels. *Ecological Modelling 440*: 109386. https://doi.org/10.1016/j.ecolmodel.2020.109386

CRRU UK (Campaign for Responsible Rodenticide Use UK) 2021 *CRRU UK Code of Best Practice; Best Practice Guidance for Rodent Control and the Safe Use of Rodenticides*. Revision August 2021. Campaign for Responsible Rodenticide Use UK. pp 36. www.thinkwildlife.org/code-of-best-practice/

Defra (Department for Environment, Food and Rural Affairs) 2009 *Spring trap and collarum test criteria*. Defra: London, UK

Dizney L, Jones PD and Ruedas LA 2008 Efficacy of three types of live traps used for surveying small mammals in the Pacific Northwest. *Northwestern Naturalist 89*: 171-180. https://doi.org/10.1898/NWN08-18.1

Dubois S, Fenwick N, Ryan EA, Baker L, Baker SE, Beausoleil NJ, Carter S, Cartwright B, Costa F, Draper C, Griffin J, Grogan A, Howald G, Jones B, Littin KE, Lombard AT, Mellor DJ, Ramp D, Schuppli CA and Fraser D 2017 Consensus principles for ethical wildlife control. *Conservation Biology 31*: 753-760. https://doi.org/10.1111/cobi.12896

EC (European Commission) 2019 Commission Implementing Regulation (EU) 2019/637 of 23 April 2019 approving cholecalciferol as an active substance for use in biocidal products of product-type 14. *Official Journal of the European Union L 109/13*. pp 6

Ennaceur A, Michalikova S and Chazot PL 2009 Do rats really express neophobia towards novel objects? Experimental evidence from exposure to novelty and to an object recognition task in an open space and an enclosed space. *Behavioural Brain Research 197*: 417-434. https://doi.org/10.1016/j.bbr.2008.10.007

EU (European Union) 2020 *Product assessment report of a biocidal product for national authorisation applications; Selontra® Product Type PT 14 Cholecalciferol*. Case number in R4BP: BC-LS050091-32. Regulation (EU) No 528/2012 concerning the making available on the market and use of biocidal products. file:///C:/Users/uzdb0086/AppData/Local/Microsoft/Windows/INetCache/Content.Outlook/9IETAM6A/105196_Selontra_fPAR__Oct_2020_non_confidential.pdf

FAWC (Farm Animal Welfare Council) 2009 *Farm Animal Welfare in Great Britain: Past, Present and Future*. FAWC: London, UK

Fenwick N 2014 *Evaluation of the humaneness of rodent capture using glue traps*. The Canadian Association for Humane Trapping: Canada

FERA 2011 *Evaluating the potential of analgesics to improve the humaneness of anticoagulant rodenticides; SID 5 Research Project Final Report (Rev. 07/10)*. Defra. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=17716

Fischer B and Lamey A 2018 Field deaths in plant agriculture. *Journal of Agricultural and Environmental Ethics 31*: 409-428. https://doi.org/10.1007/s10806-018-9733-8

Fisher P, Beausoleil NJ, Warburton B, Mellor DJ, Campion M and Booth L 2010 *How humane are our pest control tools?* (09-11326). Ministry of Agriculture and Forestry Biosecurity New Zealand Technical Paper No: 2011/01. Landcare Research: Lincoln, New Zealand

Frantz SC and Padula CM 1983 A laboratory test method for evaluating the efficacy of glueboards for trapping house mice. In: Kaukeinen DE (ed) *Vertebrate Pest Control and Management Materials, Fourth Symposium* pp 209-225. American Society for Testing and Materials: Philadelphia, USA. https://doi.org/10.1520/STP30182S

Fraser D 2008 *Understanding Animal Welfare; The Science in its Cultural Context*. Wiley-Blackwell: Oxford, UK

Galef BG and Buckley LL 1996 Use of foraging trails by Norway rats. *Animal Behaviour 51*: 765-771. https://doi.org/10.1006/anbe.1996.0081

GEA (German Environment Agency) 2021 *Liste der geprüften Mittel und Verfahren zur Bekämpfung von Gesundheitsschädlingen, Krätzmilben und Kopfläusen gemäß § 18 Infektionsschutzgesetz as of May 1, 2021*. German Environment Agency, Germany. https://www.umweltbundesamt.de/dokument/liste-ss-18-infektionsschutzgesetz. [Title translation: List of tested agents and methods for the control of health pests, scabies mites and head lice according to § 18 Infection Protection Act]

Gregory N 2004 *Physiology and Behaviour of Animal Suffering*. Blackwell: Oxford, UK. https://doi.org/10.1002/9780470752494

Himsworth CG, Feng AYT, Parsons K, Kerr T and Patrick DM 2013 Using experiential knowledge to understand urban rat ecology: A survey of Canadian pest control professionals. *Urban Ecosystems 16*: 341-350. https://doi.org/10.1007/s11252-012-0261-4

Hsieh H, Simons M, Hartman J and Dale H 2017 Effects of social housing on cannibalism in mice and rats. *International Journal of Toxicology 36*: 74-74

Jacob J and Buckle A 2018 Use of anticoagulant rodenticides in different applications around the world. In: van den Brink N, Elliott J, Shore R and Rattner B (eds) *Anticoagulant Rodenticides and Wildlife. Emerging Topics in Ecotoxicology (Principles, Approaches and Perspectives)* pp 11-43. Springer: Cham, Denmark. https://doi.org/10.1007/978-3-319-64377-9_2

Jansen P 2011 *The Goodnature® A24 automatic rat & stoat Kill Trap; evaluation of humaneness*. https://doi.org/10.1136/bmjspcare-2011-000020.72

Jolly SE, Eason CT and Frampton C 1993 Serum-calcium levels in response to cholecalciferol and calcium carbonate in the Australian brushtail possum. *Pesticide Biochemistry and Physiology 47*: 159-164. https://doi.org/10.1006/pest.1993.1074

Kenward RE and Hodder KH 1998 Red squirrels *(Sciurus vulgaris)* released in conifer woodland: the effects of source habitat, predation and interactions with grey squirrels *(Sciurus carolinensis)*. *Journal of Zoology 244*: 23-32. https://doi.org/10.1111/j.1469-7998.1998.tb00003.x

Kraaijeveld-Smit F 2015 Ethics in rodent control. In: Buckle AP and Smith RH (eds) *Rodent Pests and their Control* pp 315-329. CAB International: Wallingford, Oxfordshire, UK. https://doi.org/10.1079/9781845938178.0315

Lambert M, Vial F, Pietravalle S and Cowan D 2017 Results of a 15-year systematic survey of commensal rodents in English dwellings. *Scientific Reports 7*: 15882. https://doi.org/10.1038/s41598-017-15723-9

Littin KE and Mellor DJ 2005 Strategic animal welfare issues: ethical and animal welfare issues arising from the killing of wildlife for disease control and environmental reasons. *Revue Scientifique et Technique Office International des Epizooties 24*: 767-782. https://doi.org/10.20506/rst.24.2.1611

Littin KE, Mellor DJ, Warburton B and Eason CT 2004 Animal welfare and ethical issues relevant to the humane control of vertebrate pests. *New Zealand Veterinary Journal 52*: 1-10. https://doi.org/10.1080/00480169.2004.36384

Littin KE, O'Connor C and Eason C 2000 Comparative effects of brodifacoum on rats and possums. In: Zydenbos SM (ed) *Proceedings the 53rd New Zealand Plant Protection Conference* pp 310-315. January 2000, New Zealand. https://doi.org/10.30843/nzpp.2000.53.3701

Lund M 2015 Commensal rodents. In: Buckle AP and Smith RH (eds) *Rodent Pests and Their Control* pp 19-32. CABI International: Wallingford, UK. https://doi.org/10.1079/9781845938178.0019

Macdonald DW and Barrett P 1993 *Mammals of Britain and Europe*. Harper Collins: London, UK

MAF 2008 *Proposal to Prohibit the Sale and Use of Rodent Glueboard Traps*. Ministry of Agriculture and Forestry Biosecurity: New Zealand

Mason G and Littin K 2003 The humaneness of rodent pest control. *Animal Welfare 12*: 1-37

Meerburg BG, Singleton GR and Kijlstra A 2009 Rodent-borne diseases and their risks for public health. *Critical Reviews in Microbiology 35*: 221-270. https://doi.org/10.1080/10408410902989837

Mellor DJ and Beausoleil NJ 2015 Extending the 'Five Domains' model for animal welfare assessment to incorporate positive welfare states. *Animal Welfare 24*: 241-253. https://doi.org/10.7120/09627286.24.3.241

Mellor DJ and Reid CSW 1994 Concepts of animal well-being and predicting the impact of procedures on experimental animals. In: Baker RM, Jenkin G and Mellor DJ (eds) *Improving the Well-being of Animals in the Research Environment* pp 3-18. Australian and New Zealand Council for the Care of Animals in Research and Training (ANZCCART): Glen Osmond, South Australia, Australia

Morriss GA and Warburton B 2014 Modifying the Victor (R) Easy Set (R) Rat Trap to improve the animal welfare of stoats and ship rats trapped in New Zealand. *PLoS One 9*: e86760. https://doi.org/10.1371/journal.pone.0086760

Nakayama SMM, Morita A, Ikenaka Y, Mizukawa H and Ishizuka M 2019 A review: poisoning by anticoagulant rodenticides in non-target animals globally. *Journal of Veterinary Medical Science 81*: 298-313. https://doi.org/10.1292/jvms.17-0717

Natural England 2010 *The Animal Welfare Act 2006: What it means for wildlife*. Technical Information Note TIN072. Natural England: Sheffield, UK

Parrott D, Quy R, Van Driel K, Lurz P, Rushton S, Gurnell J, Aebischer N and Reynolds J 2009 *Review of red squirrel conservation activity in northern England*. A Report by Fera to Natural England (NECR019). Natural England: Sheffield, UK

Pearson E, Ortega YK and Ruggiero LF 2003 Trap-induced mass declines in small mammals: mass as a population index. *The Journal of Wildlife Management 67*: 684-691. https://doi.org/10.2307/3802675

PMA (Pest Management Alliance) 2017 *Code of Best Practice: Humane use of Rodent Glue Boards*. https://www.pmalliance.org.uk/codes-of-best-practice/

Prout DM and King CM 2006 The effect of handling under anaesthetic on the recapture rate of wild ship rats *(Rattus rattus)*. *Animal Welfare 15*: 63-66

PSD (Pesticides Safety Directorate) 1997 *Assessment of humaneness of vertebrate control agents*. Evaluation of fully approved or provisionally approved products, no 171. Defra and the PSD: York, UK

Pyzyna BR, Trulove NF, Mansfield CH, McMillan RA, Ray CN and Mayer LP 2018 ContraPest®, a new tool for rodent control. In: Woods DM (ed) *Proceedings of the 28th Vertebrate Pest Conference*. University of California, Davis, CA, USA. https://doi.org/10.5070/V42811054

RRAG (Rodenticide Resistance Action Group) 2018 *The UK Rodenticide Resistance Action Group: Response to ECHA public consultation on cholecalciferol.* https://circabc.europa.eu/sd/a/0d7998e3-f58b-4678-b403-3d14d4c60b53/13_RRAG%20Cholecalciferol_03_04_18%20FINAL.pdf

Ryan EA 2021 *Non-target interactions and humane evaluation of a captive bolt trap on commensal rodents*. MSc Thesis, University of British Columbia, Canada

Schlötelburg A, Geduhn A, Schmolz E, Friesen A, Baker S, Martenson N, Le Laidier G, Urzinger M, Klute O, Schröer D, Brigham A and Puschmann M 2021 *NoCheRo-Guidance for the Evaluation of Rodent Traps. Part A Break back/Snap traps*. German Environment Agency: Dessau, Germany. https://www.umweltbundesamt.de/publikationen/nochero-guidance-for-the-evaluation-of-rodent-traps

Schmolz E 2010 Efficacy of anticoagulant-free alternative bait products against house mice (*Mus musculus*) and brown rats (*Rattus norvegicus*). *Integrative Zoology 1*: 44-52. https://doi.org/10.1111/j.1749-4877.2010.00191.x

Sharp T and Saunders G 2011 *A Model for Assessing the Relative Humaneness of Pest Animal Control Methods, Second Edition*. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, Australia. http://www.daff.gov.au/animal-plant-health/welfare/aaws/humaneness-of-pest-animal-control-methods

Špur N, Pokorny B and Šorgo A 2016 Attitudes toward and acceptability of management strategies for a population of hooded crows (*Corvus cornix*) in Slovenia. *Anthrozoös 29*: 669-682. https://doi.org/10.1080/08927936.2016.1228766

Talling JC and Inglis IR 2009 *Improvements to trapping standards.* DG ENV. https://ec.europa.eu/environment/biodiversity/animal_welfare/hts/pdf/Final_report.pdf

Walther B, Ennen H, Geduhn A, Schlötelburg A, Klemann N, Endepols S, Schenke D and Jacob J 2021 Effects of anticoagulant rodenticide poisoning on spatial behavior of farm dwelling Norway rats. *Science of the Total Environment 787*: 147520. https://doi.org/10.1016/j.scitotenv.2021.147520

Zhelev G, Lyutskanov M, Petrov V, Mihaylov G, Marutsov P, Koev K and Tsvetanov TS 2013 Efficacy of a cellulose-based rodenticide for control of warfarin-resistant black rats *(Rattus rattus)*. *Bulgarian Journal of Veterinary Medicine 16*: 134-140