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Using radio frequency identification technology to track the movement of slugs within domestic garden habitats*

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Abstract. Slugs (Gastropoda: Stylommatophora) are common domestic garden inhabitants in the United Kingdom (UK) but few studies have explored the spatial behaviour of slugs within these habitats, largely due to limitations in available mark-recapture methodologies. Attempts to improve such methodologies for slugs have previously come at a high economic cost, short lifespan, and inability to detect slugs beneath the soil surface. The use of radio-frequency identification (RFID) technology has previously shown potential in overcoming these limitations, reducing the cost and impracticality of studying slug movement. However, this has yet to be applied to a domestic garden setting. This study explored the potential of RFID technology to track slug movement in a UK domestic garden. Both the common garden pests *Deroceras reticulatum* and *Arion hortensis* and the non-pestiferous *Limacus maculatus* were tagged with modest to no detrimental effects on survival at 62.5%, 25%, and 0% respectively. A novel method for the containment of *D. reticulatum* within a section of garden habitat was also assessed and found to be effective in containing 80% of slugs for a period of 67 days. RFID technology was able to identify the location of *D. reticulatum* amongst dense garden foliage and sub-soil for 67 days, enabling slug tracking within a domestic garden habitat. No homing instinct was identified in this study when attempting to induce a home territory over a period of 67 days for the species *D. reticulatum.* This study demonstrates the potential of RFID technology to track the locomotion of slugs in UK domestic garden habitats and provides an opportunity to update our knowledge on this subject by overcoming the methodological limitations associated with the high cost and impracticality of studying slugs.

Key words. RFID, locomotion, mark-recapture, spatial behaviour, domestic gardens, terrestrial molluscs, slugs

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Introduction

Slugs (Gastropoda: Stylommatophora) are common domestic garden inhabitants in the United Kingdom (UK), where they have long been considered pestiferous due to feeding on a wide range of plants (Barnes & Weil 1944). This feeding behaviour can cause substantial economic losses within agricultural and horticultural production systems as well as being a challenge faced by most home gardeners (South 1992). Not all species found in gardens negatively impact gardeners despite the common misconception that all slugs are pestiferous. Many contribute to garden ecosystems by assisting in the decomposition of organic matter (Pálková & Lepš 2008), while others are carnivores that influence ecological dynamics through predation on other invertebrates (Rowson & Symondson 2008). Understanding the abundance, distribution, and movement patterns of slugs in domestic gardens is crucial to develop targeted management strategies that conserve beneficial species and promote public awareness about their ecological roles.

The first major study of slugs in domestic garden habitats was completed by Barnes & Weil (1944), who highlighted the ecological importance of slugs in domestic gardens while also identifying key issues faced by gardeners at that time. Over the past 80 years there has been limited research into slug diversity, abundance, distribution, and movement in domestic gardens despite citizen-science techniques showing great potential in addressing this knowledge gap

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(Cavadino *et al.* 2024). However, during the same period research into control methods has increased (Crane *et al.* 2006). Slug control in domestic gardens has historically relied upon synthetic chemical molluscicides such as metaldehyde. Increased awareness of non-target effects and the withdrawal of many active ingredients in recent years means that gardeners are seeking alternative control methods (Castle *et al.* 2017; Di Blasio *et al.* 2020). Methods include biological control using nematodes such as *Phasmarhabditis hermaphrodita* (A. Schneider, 1859) (Nematoda: Rhabditida: Rhabditidae) (Pieterse *et al.* 2017; Rae *et al.* 2023) alongside cultural controls such as full barriers, relocation, and hand-removal (Royal Horticultural Society 2023). Relocation, for example, involves the removal of an individual from an undesired location, such as an area with vulnerable plants, and placing it in either a different, less-vulnerable area of the garden (Royal Horticultural Society 2023), or outside of the garden completely (Dunstan & Hodgson 2014). Despite relocation being a method recognised by organisations such as the Royal Horticultural Society, there is currently little understanding as to the efficacy of this approach for the management of pest slug species in gardens, noting that some species may exhibit homing behaviours and, therefore, may return to the location in which they were removed from. This is in part due to limited understanding of spatial behaviours, such as homing, which in-turn results from a lack of effective techniques to track slug movement combined with the high labour cost associated with observing slugs in garden environments.

Homing behaviour is recognised in a wide range of terrestrial and aquatic molluscs (Gelperin 1974; Cook 1979; Hodgson & Dickens 2012). Home territories are formed when an individual centres around the use of a single refuge, which is thought to provide shelter from physical and abiotic stress (Chelazzi 1990). This instinct has long been believed to be associated with chemoreception and the following of "trails" deposited when an individual leaves a space previously designated as "home" (Ng *et al.* 2013). However, the garden snail, *Cornu aspersum* (O.F. Müller, 1774) (Stylommatophora: Helicidae), can return home without a chemical trail when physically displaced (Dunstan & Hodgson 2014). Whether slugs have a homing instinct that does not rely on chemical trails is currently unknown. Previous research investigating slug movement has relied on mark recapture techniques such as freeze-marking where the mantle of the slug is marked using hot copper wire irons (Richter 1976), radioactive isotopes (Hakvoort & Schmidt 2002), or injected dyes into the slug (Hogan & Steele 1986; Foltan & Konvicka 2008). These techniques, however, often come with high costs and short monitoring periods, being effective between only 10 days and two months in many cases. Such techniques are also limited to identifying slugs on the soil surface. This is an important limitation when tracking slugs as many species are found beneath the soil surface during daylight hours (Douglas & Tooker 2012). One technique identified for its efficacy in long-term tracking of slug locomotion is Radio Frequency Identification (RFID). This is a method of automatic identification and data capture that can be used to identify an object or organism by transmitting digital data such as an inventory number to an RFID reader (Domdouzis *et al.* 2007). The use of RFID tags for labelling individuals has been used extensively in animals, with examples ranging from cattle (Huhtala *et al.* 2007) to fish (Roussel *et al.* 2000). In recent years, RFID use has extended to tracking smaller organisms including invertebrates (Vinatier *et al.* 2010; Pope *et al.* 2015). Slugs have also been successfully RFID tagged. Several studies have explored the potential of inserting an RFID tag into large species of slug, including the arionids *Arion vulgaris* Moquin-Tandon, 1855 (Grimm 1996; Nyqvist *et al.* 2020) and *Arion ater rufus* (Linnaeus, 1758) (Arionidae) (Ryser *et al.* 2011; Knop *et al.* 2013; Reise *et al.* 2020). These methods require an RFID tag to be implanted into the foot of a slug. This procedure has, however, not been tested for smaller slug species until relatively recently. Forbes *et al.* (2020) developed a new method for tagging *Deroceras reticulatum* (O.F. Müller, 1774) (Agriolimacidae) a small pest species at <5 cm in length (Taylor 1902–1907) by inserting the tag into the body wall. This method has facilitated *D. reticulatum* tracking in arable fields to determine species distribution and movement with high accuracy and relatively low labour cost. Use of RFID technology to track slug movement outside of agricultural environments has yet to be assessed.

This study assessed the suitability of RFID technology to monitor the spatial behaviour of UK domestic garden slug species. It investigated the effect of RFID tag insertion in two common garden-pest species (*D. reticulatum* and *Arion hortensis*) and one non-pestiferous species (*Limacus maculatus* (Kaleniczenko, 1851), Limacidae). It further evaluated a method for the containment of slugs in domestic garden habitats, analysed the effect of containment period on slug movement, explored the potential of RFID technology to track *D. reticulatum* movement in a domestic garden habitat and investigated the role of chemical cues in slug homing behaviour.

Materials and Methods

Study Organisms

The impact of RFID tagging and anaesthetisation on slug survival was assessed under laboratory conditions for two pestiferous slug species (*Deroceras reticulatum* and *Arion hortensis*) as well as one non-pestiferous species (*Limacus maculatus*). Slug species were selected due to their abundance in a survey of domestic gardens in Shropshire, UK (Tonks, unpublished data). Slugs were collected by hand searching the grounds at Harper Adams University (Shropshire, UK) on two separate occasions, 11–25 February 2020 and 16–30 January 2023, during the two-week period prior to the experiments being carried out. Identification of live slugs was carried out using morphological trait assessments (Rowson *et al.* 2014). Individuals were maintained in 250 mL circular polypropylene containers (G&S Packing UK Ltd, Ilford, UK) with four 1 mm diameter ventilation holes equally spaced around the outer edge of the container. Containers were lined with paper towel (114 mm × 115 mm) folded into quarters and moistened with 5 mL of distilled water. Lettuce (*Lactuca sativa* L. cv. Iceberg) leaves were provided as food *ad libitum*. Moistened paper towel and lettuce were replaced every 72 hours. Slugs were maintained in a temperature controlled cabinet (Panasonic Biomedical MLR-352H-PE, Loughborough, UK) set to a constant temperature of 10 °C to reflect the temperature conditions in the UK at the time of collection and an 16:8 hour light:dark photoperiod.

Radio Frequency Identification Tag Insertion

RFID tags were inserted followed the protocol developed by Forbes *et al.* (2020). Prior to RFID tag insertion, a single slug was placed into a sterilised 33 mm (H) × 44 mm (D) round polypropylene container with a 5 mm hole in the lid. Prior to introduction of slugs, containers were sterilised by submersion for 15 minutes in 1.8% v/v dilution of sodium hypochlorite (NaClO) based sterilising fluid (Milton Sterilising Fluid, Milton International, Nantes, France). Individual slugs were anaesthetised using a Corkmaster carbon dioxide (CO_2) dispenser (Sparklets, UK) and 8 g CO_2 bulb (Sparklets, UK) by slowly releasing CO_2 through the 5 mm hole into the container. The CO_2 was released into the container until the slug became fully extended, typically after a period of approximately 20 seconds for *D. reticulatum*. Individuals were then removed from the container and positioned on the left-hand thumb of the researcher; the anterior end of the slug facing the researcher's palm. The forefinger and middle finger were then placed on either side of the mantle to stabilise the slug for the duration of the procedure. The sterilised hypodermic needle of a MK165 implanter (Biomark, USA), preloaded with an 8 mm × 1.5 mm RFID tag (HPT8 tag, Biomark, USA), was then positioned at an angle of approximately 30° to the body wall of the slug (Fig. 1). Pointing anteriorly, the needle was then inserted into the body wall to a depth of 3 mm, approximately three-quarters of the way along the length of the body from the head. The needle was removed upon RFID tag insertion.

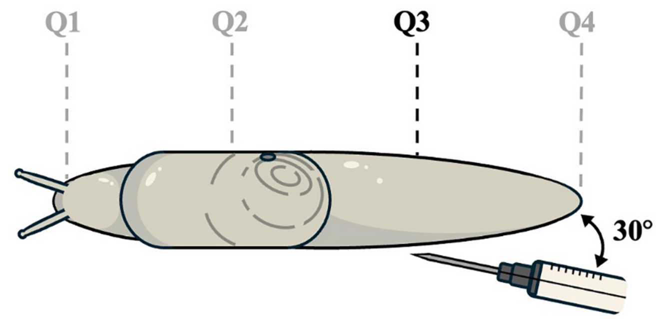

Figure 1. Position of RFID tag insertion into the body wall of the slug.

Effect of RFID Tag Insertion on Slug Survival

The effect of the RFID tag insertion was assessed through two experiments (Table 1). For both experiments, mortality was recorded every 72 hours for the duration of the experiment. Suspected death was confirmed if no response was returned after the application of mechanical stimuli using a 000 paintbrush.

Containment and Tracking of *D. reticulatum* in a Garden Environment

Six open-bottom, mesh tents (EntoNets, Atherstone, UK) measuring 1.3 m × 1.3 m were situated in a domestic garden in Shropshire, UK. The side of each tent was dug into the ground to a vertical depth of 50 cm to create an arena to contain the slugs. Within each arena, the flora consisted of common grass species (namely *Poa annua* L. and *Lolium perenne* L.), except for one refuge plant (*Gaultheria procumbens* L.; selected for its undesirable qualities as a food plant (Cates & Orians 1975; Moshgani *et al.* 2017) and shelter formed by dense, waxy foliage), and one food plant (*Viola tricolor* var. *hortensis* (DC. ex Ging.) Corb.). A total of 30 *D. reticulatum* were RFID tagged and maintained in 250 mL circular polypropylene containers (G&S Packing UK Ltd, Ilford, UK) using the methods previously described. Tagged *D. reticulatum* were maintained under controlled climatic con-

Table 1. Treatments used to assess the effect of RFID tag insertion in the species *Deroceras reticulatum, Arion hortensis,* and *Limacus maculatus.*

Experiment	Species assessed	Treatment	Replication	Duration (days)
1	*D. reticulatum*	CO_2 = Anaesthetised using CO_2 only. CO_2 + T = Anaesthetised using CO_2 and RFID tag inserted. Untreated Control = Not subject to anaesthetisation or RFID tag insertion.	*n* = 30	21
2	*D. reticulatum* *A. hortensis* *L. maculatus*	CO_2 + T = Anaesthetised using CO_2 and RFID tag inserted. Untreated Control = Not subject to anaesthetisation or RFID tag insertion.	*n* = 8	15

ditions (10 °C; 16:8 hour light:dark photoperiod; Panasonic Biomedical MLR-352H-PE, Loughborough, UK) for three days post tag insertion. On 24 February 2023, five RFID tagged *D. reticulatum* were released into each arena onto the refuge plant. The slugs remained undisturbed for 14 days following release to allow for acclimatisation to natural climatic conditions. Tracking of *D. reticulatum* began on 10 March 2023. The exact location of each slug within the arenas was recorded using a coordinate system, treating the base of the arena as a grid within which the bottom left corner formed the coordinate (0,0). The *x* coordinate was generated using the horizontal distance in cm from the *y* axis of the arena to the slug, and the *y* coordinate using the vertical distance in cm from the *x* axis to the slug (Fig. 2). All *D. reticulatum* were contained within their respective garden habitat arenas for a total period of 67 days, inclusive of the acclimatisation period. With each arena containing foliage reflecting a common garden habitat, the aim was to assess the efficacy of long-term RFID tracking of *D. reticulatum* within a representative domestic garden. The inclusion of a refuge and food plant was also used to encourage the association of the arena as a home territory. During the

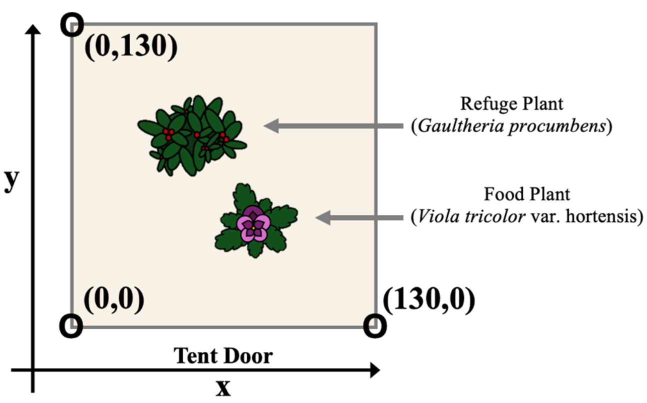

Figure 2. Bird's-eye view of the coordinate system used to locate slugs within the six open-bottom mesh tents.

67-day containment period, intensive monitoring of *D. reticulatum* was completed over a period of 14 days (10 and 23 March 2023), hereby referred to as the short-term tracking period. All slugs were scanned using a HPR Plus RFID reader and racket antenna (Biomark, USA) every 24 hours at one hour after sunset. A coordinate within the artificial housing was recorded for each slug after a hand search took place to identify precise location, following from the 10 cm read range initially achieved using the racket antenna. Bi-weekly monitoring of *D. reticulatum* was completed over a period of 39 days following the initial short-term tracking (23 March–2 May 2023), hereby referred to as the long-term tracking period. Slugs were therefore tracked using RFID technology for a total period of 53 days. All slugs were scanned using RFID technology twice weekly (Tuesday and Friday) one hour after sunset. The precise location was recorded in the same way as during the intensive monitoring period. Slugs were reported as "escaped" when they were undetected by the RFID reader following scanning of the arenas at each sample point for the remainder of the sample period. In this instance, the slug was reported as "escaped" from the first date at which the slug was not detected. Slugs were reported as "dead" when a deceased slug was located during the hand search.

Homing Instincts of *D. reticulatum*

After a period of 67 days containment, the location of all remaining slugs was recorded, and the cage containing the slugs to a specific area was carefully removed to not disturb each slug. All slugs were then displaced at a linear distance of 10 cm away from the periphery of the arena. This distance was determined based on the findings of the long-term tracking study (15–53 days), whereby the mean distance moved was 10.1 ± 3.5 cm. This distance from the periphery of the arena was therefore considered sufficient for the identification of clear directional choices made by the slug. Direction of displacement was determined using a random number generator in R Statistical Software v. 4.3.1 (R Core Team 2023), whereby each number 0–360 corresponded to the directional angle on the compass. The slugs were tracked using a HPR Plus RFID reader and racket antenna (Biomark, USA) and hand searches every six hours for a total period of 48 hours.

Statistical Analyses

All analyses were carried out using R statistical computing software (version 4.3.1; R Core Team 2023). The effect of RFID tag implantation on *D. reticulatum, A. hortensis,* and *L. maculatus* survival was analysed using a log-rank test (survival package; Therneau 2024) to compare survival distributions and Cox proportional hazards model (forestmodel package; Kennedy 2020) to estimate the relative risk of mortality for each stage of the RFID insertion procedure. Mean linear distance moved (calculated through interpolation of two consecutive tracking points) was recorded for *D. reticulatum* to assess the effect of in-garden containment and RFID tag implantation on locomotion. Mean linear distance moved was calculated for a 24-hour period to compare differences between short-term (0–14 days) and long-term (15–53 days) tracking periods. Differences in mean linear distance were analysed using a Mann–Whitney *U* test due to violations of normality and homogeneity of variance assumptions. The R package ggplot2 (Wickham 2016) was used for all data visualisation.

Results

Effect of RFID Tag Insertion on *Deroceras reticulatum*

A log-rank test was carried out to compare survival distributions for *D. reticulatum* across three stages of the RFID tag insertion procedure, untreated control, CO_2, and CO_2 + T (Fig. 3) 21 days post-tag insertion. Analysis indicated a significant difference in survival between the treatment groups ($\chi^2 = 11.5$, df = 2, $p = 0.003$, $n = 30$). A Cox proportional hazards model was fitted to estimate the relative risk of mortality for each stage of the RFID insertion procedure (CO_2 only; CO_2 + T) compared to the untreated control (Fig. 4). Survival of *D. reticulatum* was 26.3% lower for individuals subject to the whole RFID insertion procedure (CO_2 + T) compared to the untreated control group, with a Hazard Ratio (HR) of 3.18 (95% CI: 1.13–9.0) indicating a significantly increased risk of mortality compared to the untreated control ($p = 0.028$). No difference in mortality was observed between anaesthetised (CO_2) and untreated control groups, with a HR of 0.57 (95 % CI: 0.014–2.4; $p = 0.442$).

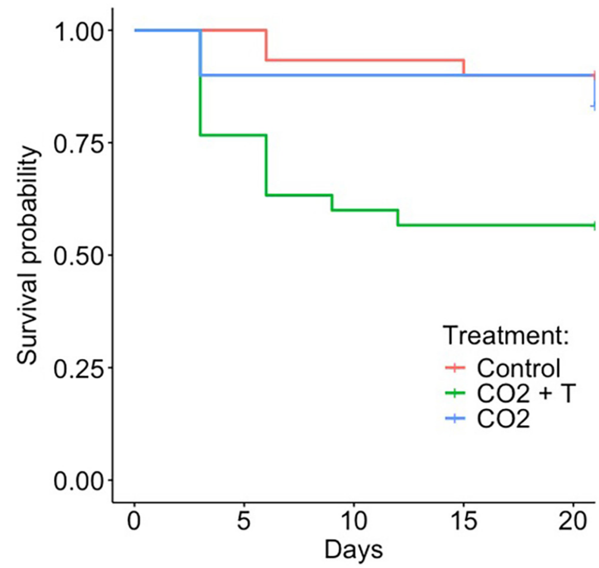

Figure 3. The effect of RFID tag insertion and anaesthetisation with CO_2 on the survival of *D. reticulatum* over a 21-day period. Control–untreated; CO_2 + T–anaesthetised using CO_2 and RFID tag inserted into the body cavity; CO_2–anaesthetised using CO_2 only, $n = 30$ per treatment.

Effect of RFID Tag Insertion on Alternate Slug Species

A log-rank test was carried out for each of the three species, *D. reticulatum*, *A. hortensis*, and *L. maculatus*, to compare survival distributions between slugs which had undergone the whole RFID tag insertion procedure (CO_2 + T) and the untreated control at 15 days post-tag insertion. Survival of *D. reticulatum* was significantly different between RFID tagged (CO_2 + T) and control groups ($\chi^2 = 6.8$, df = 1, $p = 0.009$, $n = 8$), with survival being 62.5 % lower in individuals subject to the RFID insertion procedure (Fig. 5a). Survival of *A. hortensis* was 25 % lower in RFID tagged (CO_2 + T) compared to the control group, but not significantly different overall ($\chi^2 = 2.1$, df = 1, $p = 0.1$, $n = 8$; Fig. 5b). No difference in survival was observed for *L. maculatus* between tagged and control groups (Fig. 5c).

Containment of *D. reticulatum* within a Garden Habitat Arena

Mesh tents dug to a depth of 50 cm into the ground were able to successfully confine 80% of *D. reticulatum* for a period of 67 days (Fig. 6). The largest percentage of individuals, 13.3%, escaped between 20 and 35 days post-release. After this period only one slug escaped confinement. Mortality of *D. reticulatum* reached 13.3% by the end of the 67-day period. The largest percentage of individuals, 10%, were reported dead between 32 and 39 days post-release.

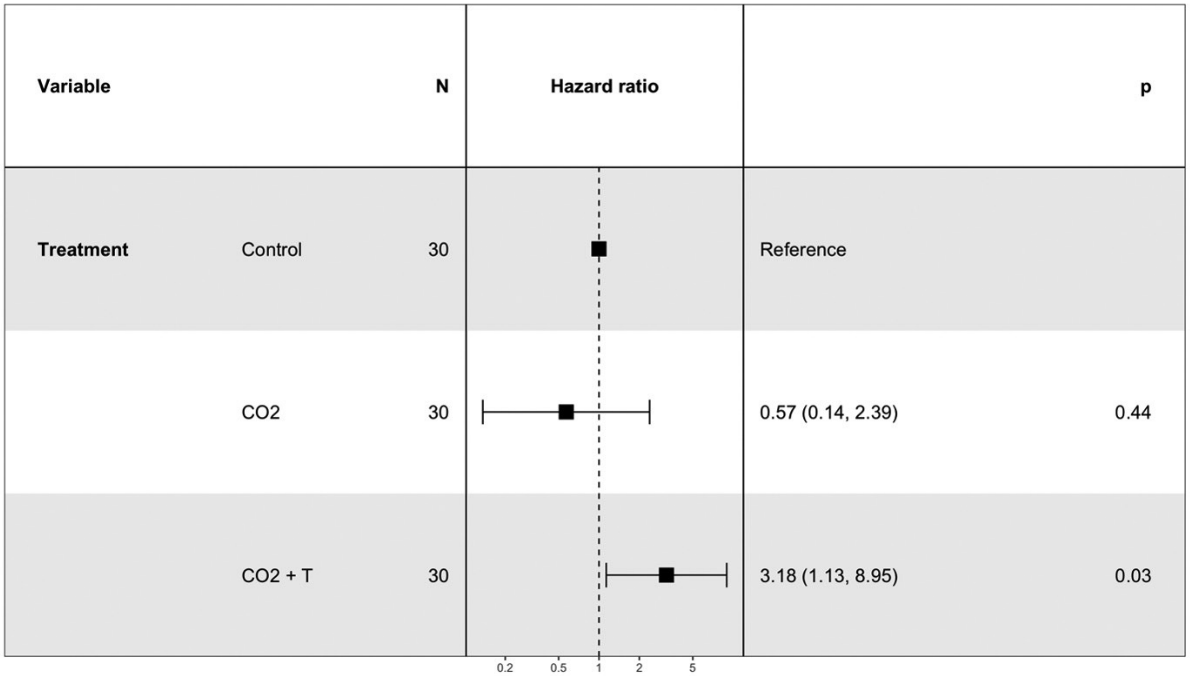

Figure 4. Hazard ratios associated with the procedure for RFID tag insertion and anaesthetisation with CO_2 for *D. reticulatum* over a 21-day period. Control–untreated; CO_2 + T–anaesthetised using CO_2 and RFID tag inserted into the body cavity; CO_2–anaesthetised using CO_2 only, n = 30 per treatment.

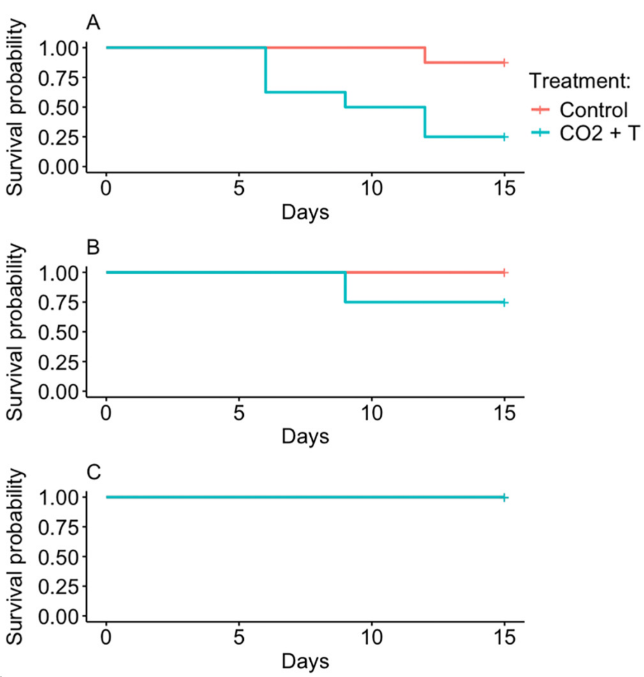

Figure 5. The effect of RFID tag insertion and anaesthetisation with CO_2 on the survival of (A) *D. reticulatum,* (B) *A. hortensis* and (C) *L. maculatus* over a 15-day period. Control–untreated; CO_2 + T–anaesthetised using CO_2 and RFID tag inserted into the body cavity, n = 8 per treatment

Tracking *D. reticulatum* within a Garden Habitat Arena

It was possible to track the locomotion of *D. reticulatum* for a period of 53 days within arenas containing domestic garden habitat using RFID tags. During the short-term tracking period (0–14 days) the mean distance moved, calculated using the sum of distance travelled over a total of 14 observations for each slug, was 107.11 ± 27.06 cm (Fig. 7).

During the long-term tracking period (15–53 days) the mean distance moved, calculated using the sum of distance travelled over a total of 12 observations for each slug, was 10.156 ± 3.534 cm (Fig. 8).

The difference in mean linear distance travelled in 24-hours by *D. reticulatum* between short-term (0 - 14 days) and long-term (15 - 53 days) tracking periods was analysed using a Mann-Whitney U test. Frequency of sampling was standardised for both short-term and long-term tracking by using bi-weekly sampling data from each to calculate mean distance travelled by individual slugs in a 24-hour period. Median distance moved was then calculated for each tracking period (short-term and long-term) due to violations of normality. Analysis showed a significant difference in linear distance travelled between short-term and long-term tracking periods (W = 149, p = 0.001). Linear distance travelled during the short-term tracking

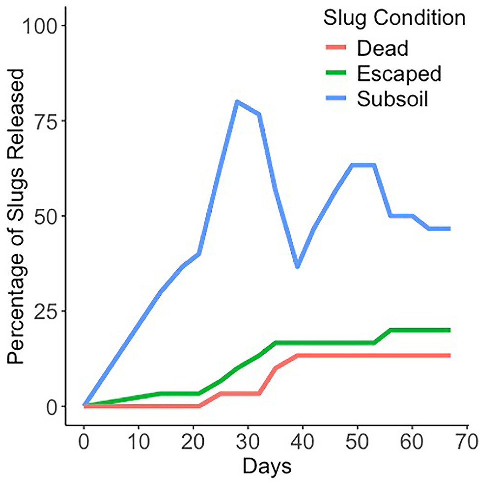

Figure 6. The efficacy of mesh tents, dug into the ground to a vertical depth of 50 cm, to contain RFID tagged *Deroceras reticulatum* (*n* = 30), over a 67-day period. Dead: individuals physically found within the containment that were unresponsive to mechanical stimuli when gently touched with a 000 paintbrush. Subsoil: individuals identified as within the containment using RFID, but not physically found above the soil surface. Escaped: individuals persistently not identified as within the containment using RFID, or physically found.

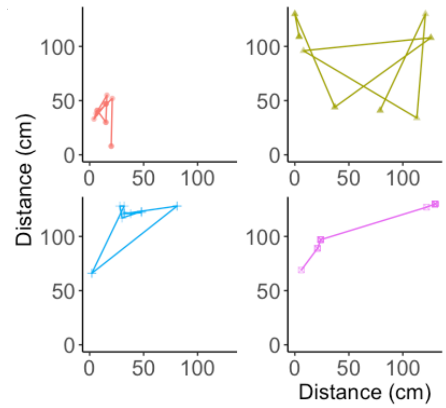

Figure 7. Individual movement of *D. reticulatum* within one of six identical arenas over a period of 14 days (10–23 March 2023). Location was recorded at 24-hour intervals and was identified using a combination of RFID technology and hand-searches. Each point represents the location at which an individual slug was identified, with each different line colour representing a different slug. Points connected by lines indicate consecutive locations of an individual but not the actual path taken by the slug.

period (Median = 4.64 cm, IQR = 9.38) was greater than that observed over the long-term tracking period (Median = 0.04 cm, IQR = 0.56), with an effect size of 0.53, suggesting a substantial difference in movement patterns between the tracking periods.

Homing Instincts of *D. reticulatum*

It was possible to track the movement of *D. reticulatum* within a UK domestic garden when containment within an arena was removed. No individuals returned to the arena used to artificially enforce a "home territory" within the 48-hour period post-displacement at 10 cm from the periphery of the arena. At the end of the 48-hour period, 20% of the *D. reticulatum* (*n* = 30) were found and identified as alive. Mean distance moved over the 48-hour period was calculated to be 57.541 ± 6.247 cm using the sum of distance travelled for each of the slugs found (Fig. 9).

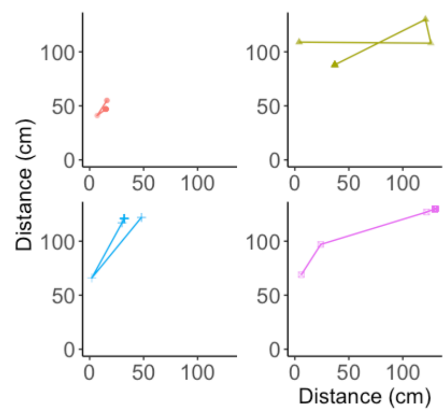

Figure 8. Individual movement of *D. reticulatum* within one of six identical arenas over a period of 39 days (23 March–2 May 2023). Location was recorded at twice-weekly intervals and was identified using a combination of RFID technology and hand-searches. Each point represents the location at which an individual slug was identified, with each different line colour representing a different slug. Points connected by lines indicate consecutive locations of an individual but not the actual path taken by the slug.

Discussion

Recent developments in RFID technology have led to this approach being used to study slug spatial behaviour. While RFID technology has been used to track the movement of *D. reticulatum* in agricultural landscapes (Forbes *et al.* 2020), the full potential of this technology has not pre-ity after a period of six days. These findings support the suggestion of internal organ damage resulting from the RFID tag insertion procedure and that this may be associated with starvation as the cause of mortality (Forbes *et al.* 2020). Although Forbes *et al.* (2020) demonstrated that smaller slug species could be tracked using RFID technology it focussed on a single pestiferous species

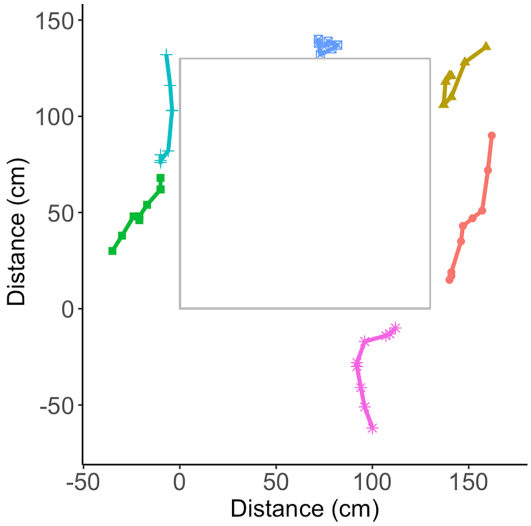

Figure 9. Map overlaying movement of *D. reticulatum* in proximity of six identical arenas over a period of 48 hours. Location was recorded at six hourly intervals and was identified using a combination of RFID technology and hand-searches. Each point represents the location within which an individual slug was identified, with each colour and point type representing a different slug. Points connected by lines indicate consecutive locations of an individual but not the actual path taken by the slug. The box within the axis represents the arena contained by a mesh tent, which was used to simulate an artificially induced "home territory".

whereas we assessed the application of this technology for two previously unstudied species. *Limacus maculatus* (green cellar slug) is a non-pestiferous, large-bodied slug typically less than 9.5 cm in length (Langeraert *et al.* 2021). *Limacus maculatus* has a much larger body size than *D. reticulatum* (<5 cm at maturity) and *A. hortensis* (<4 cm). This study found it possible to tag *L. maculatus* with RFID technology with no mortality reported within the first 15 days post-RFID insertion. Comparatively low mortality of *L. maculatus* is likely related to their large body size, with the likelihood of internal organ damage following the insertion of an RFID tag consequently being lower than that for the smaller species, *D. reticulatum* and *A. hortensis*. Despite this, 33.3% of individuals rejected the RFID tag, pushing it out of the body cavity, although the reasons for this are not known. *Arion hortensis* (the garden slug) is a common pest of UK domestic gardens. It is a small slug, at 2–4 cm in length at maturity, being slightly smaller compared to the <5 cm body length of *D. reticulatum* (Mc Donnell *et al.* 2008; Rowson *et al.* 2014). *Arion hortensis* collected and used in this study however, had an average body length of <1 cm, a possible artefact of the time of year of the study. Despite its smaller body size, it was possible to successfully to tag *A. hortensis*. The comparatively low rate of mortality post-RFID implantation in *A. hortensis* compared to *D. reticulatum* may suggest differences in the internal anatomy of the digestive gland and crop or be influenced by the differing life stages between the species.

Containment of *D. reticulatum* within a Garden Habitat Arena

Mesh tents acting as artificial housing in this study were able to contain 80 % of *D. reticulatum* for a period of 67 days without significant losses. Any lack of detection or escape by *D. reticulatum* was most likely a result of slugs moving to a depth of >50 cm beneath the soil surface (the depth of the tent perimeter), or by residing at a depth beyond that identifiable by the RFID scanner (approximately ≥20 cm; Forbes *et al.* 2020). Unseasonably warm temperatures (20 °C, May 2023) during the experimental period may have led to slugs moving to depths greater than that which the arena was dug to (>50cm beneath the soil surface). Previous research has recorded slug activity, reported as feeding damage to underground baits, at depths of more than 38 cm beneath the soil surface (Stephenson 1967). Whilst species was not recorded and associated with sub-soil depth, anecdotal evidence from this study linked these findings to key potato pest species, such as *D. reticulatum* (previously *Agriolimax reticulatus*), *A. hortensis* and *Tandonia budapestensis* (previously *Milax budapestensis*; (Stephenson 1967). Results from the present study indicate that mesh tents provided a suitable method for the containment of *D. reticulatum* within a specified area of domestic garden habitat. While there is no single recognised method for the long-term containment of slugs within an area of natural habitat, such as a domestic garden the use of mesh tents appears to be simple and effective. Previously open top aluminium arenas dug to a depth of up to 30 cm below the soil surface have been used (Cook *et al.* 1997; Frank & Barone 1999). These aluminium arenas have typically been used for short-term experiments lasting 3–30 days and often relied on the aluminium being electrically charged using an eternal battery to avoid slug escape, making this a resource intensive approach. Other studies have used Fluon (Polytetrafluoroethylene) painted around the inner rims of pot-based arenas to act as a barrier to slug movements into or out of the experimental containers (Thomas *et al.* 2009). Whilst in many cases acting as a relatively successful barrier, the use of Fluon has clear drawbacks including its high toxicity when wet and degradation over time, especially in outdoor conditions.

Tracking *D. reticulatum* within a Garden Habitat Arena

This study confirms the suitability of RFID technology to study the spatial behaviour and locomotion of *D. reticulatum* within domestic gardens habitats. RFID technology has previously been used to track the movement of this slug species within an arable field (Forbes *et al.* 2020). Furthering the work of Forbes *et al.* (2020), the present study demonstrates that it is possible to track tagged individuals across a range of habitat types, including dense fauna associated with domestic gardens. Using RFID technology, it was possible to successfully track the tagged *D. reticulatum* at regular intervals up to 70 days post-tag insertion (3 days containment in controlled conditions + 67 days containment in artificial arenas). This period of successful tracking exceeds that of previous studies (e.g. Richter, 1976). Mean distance travelled in 24 hours was significantly different between short-term (0–14 days) and long-term (15–53 days) confinement. Movement of *D. reticulatum* within domestic gardens has not previously been studied. However, Forbes *et al.*, (2020) found mean distance travelled by *D. reticulatum* when unconfined within an arable field to be between 40-60 cm per hour. The distance reported by Forbes *et al.*, (2020) is considerably greater than that observed in this study, where mean distance travelled by *D. reticulatum* when unconfined within a domestic garden was 57.541 ± 6.247 cm over 48 hours, approximately 1.2 cm per hour. Several factors may influence the reduced speed of movement in this study, including number of slugs present in the study area (Ellis *et al.* 2020), reduced number of predators (Ellis *et al.* 2020), and ambient temperature (Wareing & Bailey 1985), as well as affinity with the area as a home territory (Chelazzi 1990). Reduced speed of movement in domestic gardens further increases the challenge of tracking slug locomotion, with longer monitoring periods likely being most beneficial for the assessment of the extent of slug locomotion. The use of RFID technology overcomes some of the limitations associated with the assessment of slug spatial behaviour in domestic gardens, such as labour costs, and human error associated with traditional mark recapture. With the first known investigation into slugs in UK domestic gardens being that of (Barnes & Weil 1944) and only recent citizen-science approaches to garden-slug investigations being conducted (Cavadino *et al.* 2024), RFID technology may provide an opportunity to update our understanding of garden slug spatial behaviour, without the constraints of traditional mark recapture techniques.

Homing instincts of *D. reticulatum*

When displaced 10 cm from the periphery of the artificial home all slugs moved in a direction away from the artificial home for the study period of 48 hours. Several factors may have contributed to this behaviour. An arena consisting of a mesh tent, within which *D. reticulatum* were confined for a period of 67 days prior to this experiment, was used as the slugs' "home territory". This study aimed to artificially induce a "home territory" on the individuals by maintaining them within a 1.3 × 1.3 m confined arena, which provided the key aspects recognised in the selection of a "home". The habitat included a common and abundant food source, shelter, moisture and protection from predators. The results of this study may then indicate that it is not possible to artificially induce a "home territory" for the slug species *D. reticulatum* with our current understanding of slug behaviour. One factor which may explain the lack of home territory adoption in this study could be slug sensitivity to the disturbance caused during the removal of tents enclosing the artificial arenas. This study relied on the use of tents, dug to a depth of 50 cm below the soil surface, for slug containment within an arena. During their removal, the soil at the periphery of the arena was disturbed, which may have deterred slugs from crossing into the arena space. Another potential explanation is that the selection of food plants inside of the arena were not favoured enough to encourage the slugs to return. Finally, unseasonably warm weather, with temperatures exceeding 20 °C, may have also influenced slug behaviour. During periods of warm weather, slugs will travel in search of moisture to avoid desiccation (Prior 1985). Despite all known features of a good home being achieved, the lack of self-selection may mean the artificial home was never considered a true "home" site. Therefore, when containment was removed and the slugs were displaced, individuals moved with the intent of searching for new resources. Further research is required to explore the influence of food preference and disturbance in slug territorial and homing behaviour.

During movement, slugs secrete mucus from the pedal gland at the front of the sole (Smith 2010). This mucus primarily assists slug movement (Denny 1981), but these mucous trails also provide chemical cues that play a role in directional behaviour (Gelperin 1974; Cook 1979, 1992). By displacing *D. reticulatum* 10 cm from the periphery of the arena to avoid generation of mucous trails, this study suggests that trail-based chemoreception may play an important role in the homing behaviour and orientation of slugs. Whilst research into the homing instincts of other slug species, notably *Limax* spp. (Cook 1979, 1992; Cook *et al.* 1997), has been extensively researched in the sterile conditions of the lab, the in-situ application of these behaviours remains unclear. Only one study was conducted in-field on *Limax pseudoflavus*, using time lapse cinematography, where individuals tended to home upwind, but the direction of leaving their home was not correlated to wind direction (Cook 1980). Further research would be required to understand the chemical interactions between slugs and their trails to truly understand the in-situ application and mechanisms of a homing instinct in *D. reticulatum*. Despite this, the findings of this study overall support that, unlike snails, the relocation of pestiferous species (Royal Horticultural Society 2023) is likely to be an effective method of management for slugs in domestic gardens.

Conclusion

This study identifies the potential of RFID technology to be used to assess the locomotive behaviours of slugs in UK domestic gardens. Using the method developed by (Forbes *et al.* 2020) it is possible to RFID tag the abundant garden pest species *Deroceras reticulatum* and *Arion hortensis,* as well as the large-bodied non-pestiferous species *Limax maculatus.* RFID technology can be used to aid the tracking of multiple *D. reticulatum* within dense garden foliage, and sub-soil surface for a period of 53 days. RFID technology now provides an opportunity to further our knowledge on this subject, by overcoming the methodological limitations associated with studying slugs in domestic gardens.

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