Evaluating the efficacy of tagging adhesives for insect tracking

by Breen, L.C.R., Roberts, J.M. and Pope, T.

Breen, L.C.R., Roberts, J.M. and Pope, T. (2026) 'Evaluating the efficacy of tagging adhesives for insect tracking', *Agricultural and Forest Entomology*.

Received: 16 December 2025 | Accepted: 17 March 2026

DOI: 10.1111/afe.70047

SHORT COMMUNICATION

Agricultural and Forest Entomology

Evaluating the efficacy of tagging adhesives for insect tracking

Leona C. R. Breen | **Joe M. Roberts** | **Tom W. Pope**

Entomology Group, Centre for Crop and Environmental Science, Harper Adams University, Newport, UK

Correspondence
Tom W. Pope, Entomology Group, Centre for Crop and Environmental Science, Harper Adams University, Newport, Shropshire TF10 8NB, UK.
Email: tpope@harper-adams.ac.uk

Abstract

1. Ground beetles (Carabidae) are important predators and ecosystem service providers in agricultural landscapes, yet understanding their movement ecology remains challenging due to methodological limitations in tracking individual insects.
2. Radio-frequency identification (RFID) technology offers a promising approach for monitoring beetle movements, but successful implementation requires reliable tag attachment. We evaluated five adhesive types (water-based polyvinyl acetate, latex-based cosmetic adhesive, low-viscosity cyanoacrylate, gel-viscosity cyanoacrylate and two-part epoxy resin) for the strength of RFID tag adhesion on carabid beetles across three genera (*Harpalus*, *Leistus* and *Poecilus*).
3. Using a Gamma generalised linear model (GLM) with a log link, we found significant differences among adhesive types. Araldite epoxy provided the strongest adhesion (mean separation mass = 110.2 ± 58.2 g), significantly exceeding all other adhesives.
4. Light abrasion of the elytra significantly improved adhesion in *Leistus rufomarginatus*, with sanded surfaces showing a 2.5-fold greater separation mass than smooth surfaces. We recommend using a two-part epoxy resin with light elytra abrasion to maximise the strength of RFID tag adhesion in studies on carabids.

KEYWORDS

adhesive, Carabidae, insect tracking, movement ecology, radio-frequency identification, RFID, tag retention

INTRODUCTION

Ground beetles (Coleoptera: Carabidae) are among the most abundant and functionally important arthropod predators in temperate agroecosystems (Kromp, 1999; Lövei & Sunderland, 1996). With over 40,000 described species worldwide, carabids provide ecosystem services including biological control of agricultural pests and consumption of weed seeds (Kulkarni et al., 2015). Individual beetles may consume hundreds of aphids, slugs or weed seeds daily, contributing to pest suppression services valued at billions of dollars annually in agricultural systems globally (Symondson et al., 2002). Understanding the movement ecology of these beneficial insects is essential for optimising conservation biological control strategies and maintaining their populations in increasingly fragmented agricultural landscapes. Despite their ecological importance, tracking individual ground beetle movements presents substantial methodological challenges. Traditional mark-recapture studies using pitfall traps provide only point-location data at discrete time intervals, fundamentally limiting inference about movement paths, habitat use and individual beetle behaviour (Allema et al., 2014; Baars, 1979; Spence & Niemelä, 1994). Direct observation offers an alternative approach for recording fine-scale movement trajectories but is constrained by short observation periods and the limited number of individuals that can be followed simultaneously (Růžičková & Elek, 2023). The development of miniaturised tracking technologies has begun to address these limitations, with four primary methods available for terrestrial arthropods: (1) active radio telemetry, (2) harmonic radar, (3) passive radio-frequency identification (RFID) and (4) GPS tracking (Kissling et al., 2014). Each technology presents distinct trade-offs between detection range, tag weight, battery life and capacity for individual identification.

Active radio telemetry offers detection ranges of 100–500 m at ground level but requires transmitters weighing at least 150–200 mg, restricting application to larger insects exceeding a 1 g body mass (Růžičková & Veselý, 2016). Harmonic radar provides detection up to 1 km with lightweight tags (<15 mg) but cannot distinguish among individuals (Osborne et al., 1997). GPS tracking can provide precise location data when researchers follow insects and record positions using handheld devices (Fernández et al., 2016), but attachment of GPS receivers to insects remains impractical due to tag mass constraints. Passive RFID technology represents a promising intermediate solution, with tags weighing as little as 5 mg depending on encapsulation, an unlimited operational lifespan (requiring no internal power source) and the capacity for individual identification through unique transponder codes (Streit et al., 2003). The principal limitation of passive RFID is its short detection range, with standard tags requiring passage within approximately 5 cm of reader antennae, though prototype UHF systems have achieved 1.5 m detection distances (Barlow et al., 2019). For ground-dwelling beetles that move through complex vegetation and soil microhabitats, this range limitation necessitates dense antenna arrays or gate-based detection systems. Despite these constraints, Blight et al. (2023) successfully demonstrated RFID tracking of carabid beetles (Coleoptera: Carabidae) *Poecilus sericeus* Germar and *Acinopus picipes* Olivier in Mediterranean grassland using four-antenna detector arrays, detecting 25 of 27 tagged individuals over a seven-day period. However, detection probability declined substantially after the first week, highlighting the importance of secure tag attachment for longitudinal studies.

Successful implementation of any external tracking technology on insects fundamentally depends on reliable tag attachment. The insect cuticle presents inherent challenges for adhesive bonding due to its multilayered structure and hydrophobic surface properties (Vincent & Wegst, 2004). The outermost epicuticle (<4 μm thick) is covered by crystalline waxes predominantly consisting of long-chain hydrocarbons, fatty acids and methyl-branched alkanes that create high water contact angles and reduce surface energy, resulting in poor wetting by adhesives (Gorb, 2008). Four mechanisms contribute to wax-mediated adhesion failure: (1) micro-roughness from wax crystals reduces contact area; (2) wax crystals detach and contaminate adhesive surfaces; (3) porous wax coverage absorbs adhesive fluids; and (4) lipophilic adhesive components may dissolve the waxy layer (Voigt & Gorb, 2008). Cyanoacrylate adhesives (i.e. superglues) remain the most widely used option for insect tag attachment, with commercial formulations including Krazy Glue, Loctite and Gorilla Super Glue demonstrating equivalent bond strength when properly applied (Boiteau et al., 2009). However, adhesive performance varies substantially among insect species and body regions. Boiteau et al. (2009) reported >85% tag retention for 4–5 days on Colorado potato beetle, *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae), but only approximately 50% retention on plum curculio, *Conotrachelus nenuphar* Herbst (Coleoptera: Curculionidae), attributing this difference to the more sculptured cuticle surface of the latter species. Surface preparation through light abrasion to remove epicuticular waxes can dramatically improve adhesion, with Lee et al. (2013) demonstrating that sanding the pronotum of the brown marmorated stinkbug, *Halyomorpha halys* Stål (Hemiptera: Pentatomidae) increased bond strength to 160–190 g force compared to unprepared cuticle.

Beyond adhesive strength, welfare considerations increasingly influence methodological choices in insect tracking studies. Batsleer et al. (2020) carried out a systematic review that identified that tag impacts were quantified in only 12% of 173 surveyed arthropod telemetry papers, with 40% completely disregarding potential welfare effects. The widely cited ‘5% rule’ for tag weight, where it is recommended that tags not exceed 5% of body mass, originated from vertebrate telemetry and lacks empirical validation for arthropods. Tag-to-body mass ratios in published insect studies range from 2% to over 100%, with effects proving highly species- and context-specific (Kissling et al., 2014). Kaláb et al. (2021) demonstrated in crickets that tag effects are modulated by environmental temperature, with movement impairment most pronounced at low temperatures. For carabids specifically, Blight et al. (2023) found no significant short-term behavioural effects of passive RFID tags, though a non-significant trend towards shorter displacements was observed. The adhesive application itself may also affect insect welfare and behaviour. For example, cyanoacrylate adhesives cure exothermically and produce irritant vapours, while their low viscosity formulations risk spreading beyond the intended attachment site to obstruct spiracles and inhibit movement. This could impair gas exchange and induce physiological stress, potentially confounding behavioural observations. Gel formulations of cyanoacrylates offer more controlled application but may sacrifice bond strength compared to liquid formulations.

The target genera for carabid tracking studies span diverse ecological strategies. *Pterostichus* and *Poecilus* species are predominantly predatory, consuming slugs, aphids and other soft-bodied invertebrates, with *Pterostichus melanarius* representing the most abundant carabid in European arable land (Luff & Rushton, 1989). *Harpalus* species are primarily granivorous, actively consuming seeds of agricultural weeds including lambsquarters, pigweed and foxtail (Kulkarni et al., 2015). *Leistus* species are more specialised woodland predators using setal trap mechanisms to capture springtails, generally inhabiting mesic habitats (Bauer, 1989). These genera differ substantially in body size, cuticle texture and surface properties, suggesting that optimal tagging protocols may vary among taxa. Here, we evaluate five commercially available adhesives representing three chemical classes (water-based polyvinyl acetate, cyanoacrylate and epoxy) for their efficacy in attaching RFID tags to carabid beetles. We compare adhesive performance across four species with contrasting ecological characteristics and assess whether light abrasion of the elytra surface improves bond strength. Our objectives were to: (1) identify the most effective adhesive for RFID tag attachment; (2) determine whether surface preparation enhances adhesion; and (3) develop practical recommendations for researchers implementing RFID tracking of ground beetles.

MATERIALS AND METHODS

Study species and collection

Beetles were collected by hand from agricultural land at Harper Adams University, Shropshire, UK (52°46′ N, 2°26′ W) during May–July 2024. We tested adhesive performance on four carabid species representing three genera with contrasting body sizes and ecological strategies: *Harpalus affinis* Schrank (body mass 50–80 mg; granivorous; $n = 9$), *Harpalus rufipes* DeGeer (body mass 80–120 mg; granivorous; $n = 8$), *Leistus rufomarginatus* Duftschmid (body mass 30–50 mg; specialist predator; $n = 21$) and *Poecilus cupreus* (L.) (body mass 60–100 mg; generalist predator; $n = 15$). Beetles were maintained in individual containers with moist tissue paper and provided with cat food for at least 48 h before experiments to ensure standardised condition.

Adhesives

Five adhesive types representing three chemical classes and viscosities were evaluated in this experiment: (1) water-based polyvinyl acetate (PVA Glue, Tallon International, Coventry, UK); (2) latex-based cosmetic adhesive (Eyelash Glue, Noon's Up, Seoul, South Korea); (3) low-viscosity cyanoacrylate (Loctite Precision Superglue, Henkel Adhesive Technologies, Hemel Hampstead, UK); (4) gel-viscosity cyanoacrylate (Loctite Gel Formulation Superglue, Henkel Adhesive Technologies, Hemel Hampstead, UK); and (5) two-part epoxy resin (Araldite, Huntsman International LLC, Salt Lake City, USA). Glass encapsulated RFID tags (8 mm length × 1.4 mm diameter, mass 90 mg) (Swiss Plus ID, Elmswell, UK) were attached to the posterior third of the right elytron using a standardised 2 mm diameter adhesive droplet. Tags were positioned to avoid the elytral suture and lateral margins where spiracles are located. Beetles were euthanised by freezing at -20°C to minimise physical damage before attachment and allowed 24 h for adhesive curing before testing. Bond strength was quantified as the mass required to separate the tag from the elytra. Beetles were secured ventral-side-up in a foam-lined holder and incrementally increasing weights were suspended from the attached tag via a fine wire loop until bond failure occurred. The maximum mass at separation was recorded. For replicates where the maximum available test weight (259 g) was reached without bond failure, observations were recorded as right-censored (i.e. failure did not occur by 259 g, so the failure threshold is >259 g). To assess the effect of surface preparation, we compared smooth (unmodified) versus sanded elytra in *Leistus rufomarginatus*. Sanding involved gentle abrasion with 600-grit sandpaper (3–4 strokes) to disrupt the epicuticular wax layer without damaging underlying cuticle.

Statistical analysis

All analyses were carried out using R v4.3.2 (R Core Team, 2024) using the tidyverse for data wrangling and visualisation (Wickham et al., 2019). Separation mass (g) was analysed using Gamma generalised linear models (GLMs) with log link function. The main analysis included data from smooth elytra across four species (*Harpalus*, *Leistus*, *Poecilus*) with adhesive type and species as fixed factors. Effects were assessed using likelihood ratio (LR) χ^2 tests comparing nested models from the car package (Fox & Weisberg, 2019). Post-hoc pairwise comparisons among adhesive types used Tukey's HSD test on log-transformed separation mass via the emmeans package (Lenth & Piaskowski, 2025). Elytra condition effects were analysed for *Leistus rufomarginatus* using Gamma GLMs with adhesive type, elytra condition (smooth vs. sanded) and their interaction as predictors. Right-censored observations (bond did not fail at maximum test weight) were excluded from analysis, and results for the strongest adhesive-surface combinations should therefore be interpreted as conservative minimum estimates.

RESULTS

Adhesive bond strength

Adhesive type significantly affected tag separation mass (Gamma GLM: LR $\chi^2 = 22.26$, df $= 4$, $p < 0.001$; Figure 1). Two-part epoxy resin provided substantially stronger adhesion than all other adhesives, with mean separation mass of 110.15 ± 58.16 g (mean ± SD) compared to 8.62 ± 13.94 g for water-based polyvinyl acetate, 17.09 ± 9.98 g for latex-based cosmetic adhesive, 36.13 ± 27.73 g for low-viscosity cyanoacrylate and 30.65 ± 28.89 g for gel-viscosity cyanoacrylate. Species did not significantly influence separation mass (LR $\chi^2 = 7.13$, df $= 3$, $p = 0.068$).

Elytra surface preparation

Light abrasion of *Leistus rufomarginatus* elytra significantly improved adhesive bond strength (LR $\chi^2 = 5.22$, df $= 1$, $p = 0.022$; Figure 2). Sanded surfaces yielded mean separation mass of 60.76 ± 59.81 g compared to 24.19 ± 34.32 g for smooth surfaces, which was a 2.51-fold improvement. Both adhesive type (LR $\chi^2 = 25.60$, df $= 4$, $p < 0.001$) and elytra condition showed significant main effects, but their interaction was not significant (LR $\chi^2 = 6.15$, df $= 4$, $p = 0.189$), indicating that sanding improved adhesion consistently across all adhesive types.

DISCUSSION

This study provides the first systematic evaluation of adhesive efficacy for RFID tag attachment to ground beetles, addressing a critical methodological gap in carabid movement ecology. Our findings demonstrate that adhesive selection profoundly affects the strength of tag adhesion, with two-part epoxy resin providing separation masses approximately 13-fold higher than water-based polyvinyl acetate and 3 to 6-fold higher than cyanoacrylate formulations. Surface preparation through light elytra abrasion further improved adhesion 2.5-fold, supporting the hypothesis that disruption of epicuticular waxes enhances adhesive bonding (Lee et al., 2013). Low-viscosity cyanoacrylates should be used with caution as they may spread beyond the intended attachment site. Our findings corroborate previous work on insect tag attachment. Boiteau et al. (2009) reported >85% tag

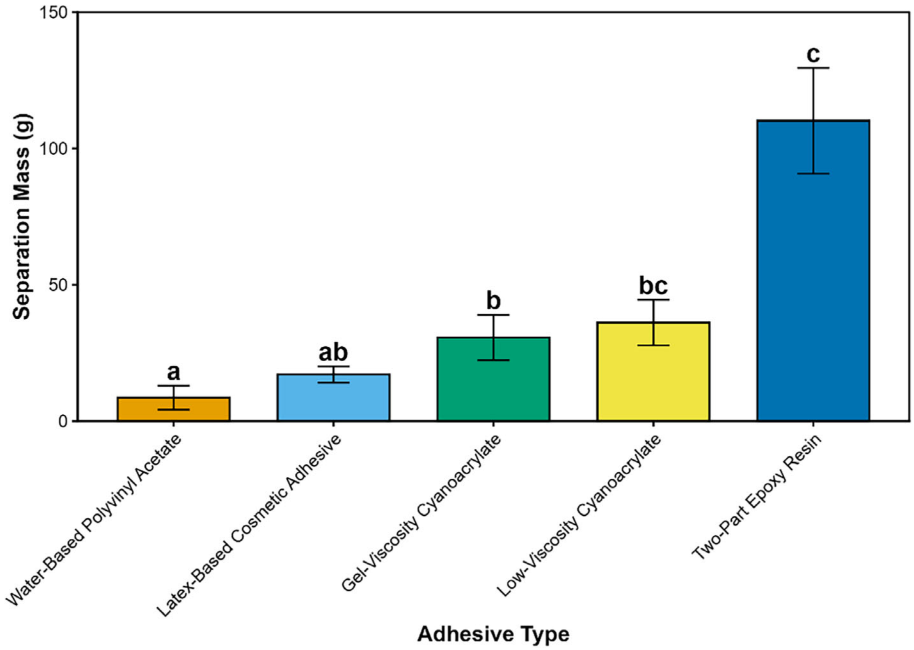

FIGURE 1 Mean separation mass (g) for five adhesive types tested on carabid beetles with smooth elytra ($n = 53$). Error bars represent ±1 SE. Letters indicate Tukey HSD significance groups ($\alpha = 0.05$); bars sharing the same letter are not significantly different. Adhesive type significantly affected separation mass (Gamma GLM: LR $\chi^2 = 22.26$, df $= 4$, $p < 0.001$).

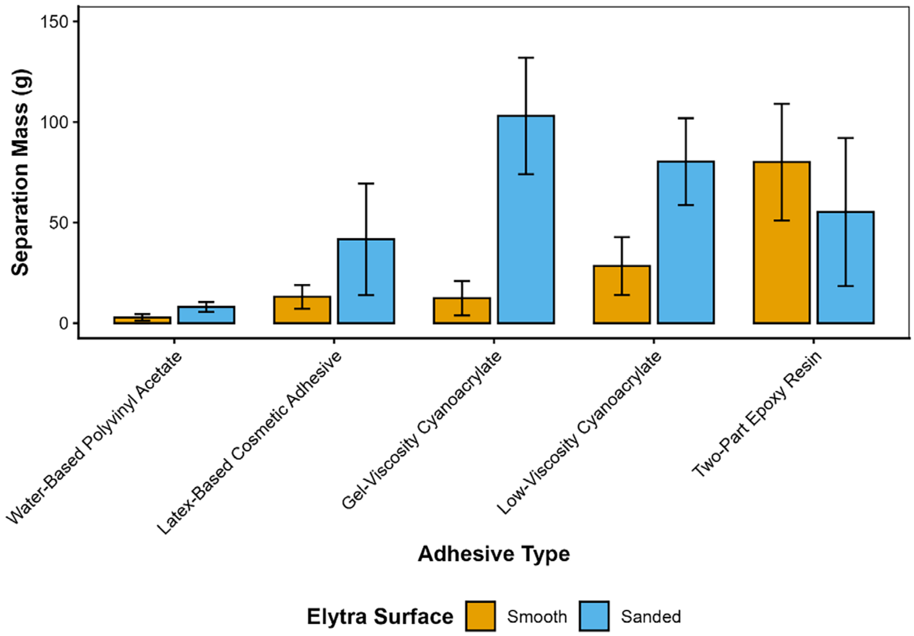

FIGURE 2 Effect of elytra surface preparation on adhesive bond strength in *Leistus rufomarginatus* ($n = 43$). Mean separation mass (g) shown for smooth (orange) and sanded (blue) elytra across five adhesive types. Error bars represent ±1 SE.

retention for 4–5 days on Colorado potato beetle using cyanoacrylate adhesives, while Lee et al. (2013) demonstrated that sanding the pronotum of *Halyomorpha halys* increased bond strength to 160–190 g force. The separation masses we observed for two-part epoxy resin (110.2 ± 58.2 g) on carabids are comparable to these values, suggesting that two-part epoxy provides adequate strength of adhesion for multi-day field studies. Importantly, our comparison across five adhesive types allows researchers to make informed choices based on their specific study requirements rather than relying on single-adhesive protocols.

The performance of two-part epoxy resin aligns with its chemical and mechanical properties. These adhesives form cross-linked polymer networks through curing reactions, creating strong covalent bonds and mechanical interlocking with surface irregularities (Kinloch & Hunston, 1987). Unlike cyanoacrylates, which cure rapidly through moisture-initiated polymerisation, epoxies allow repositioning during application and achieve maximum strength only after complete curing (typically 24 h). This extended working time facilitates precise tag placement without compromising bond integrity. Beyond bond strength, practical considerations influence adhesive selection for field studies. Two-part epoxy requires mixing immediately before application and has a limited working time (typically 5–10 min), which may constrain throughput when tagging large numbers of beetles. Cyanoacrylates offer rapid curing but risk spreading to unintended areas, particularly the low-viscosity formulations. Gel-viscosity cyanoacrylate may represent a practical compromise, offering reasonable bond strength (30.6 ± 28.9 g) with controlled application. However, gel cyanoacrylates require a minimum curing time of 12–24 h under dry conditions before beetles are released as premature release into humid microhabitats (soil, leaf litter) substantially increases the risk of tag loss (Růžičková & Veselý, 2016). When adequately cured, gel cyanoacrylate bonds can persist for weeks and tags can be recovered at the conclusion of experiments following recapture (Růžičková & Veselý, 2016). Researchers should also consider that field conditions (e.g. humidity, temperature and substrate contact) may affect adhesive performance differently than laboratory conditions. Soil particles adhering to partially cured adhesive could potentially weaken bonds, while humid conditions may accelerate cyanoacrylate curing before optimal tag positioning is achieved.

Although the species effect on adhesion strength was not statistically significant, the observed interspecific variation likely reflects differences in cuticle properties that warrant consideration when selecting tagging protocols. Carabid beetles exhibit substantial diversity in elytral surface topography, ranging from highly polished iridescent surfaces in some *Poecilus* species to rugose sculptured surfaces in many *Harpalus* (Lindroth, 1974). Surface micro-roughness affects adhesive performance through multiple mechanisms: increased contact area enhances mechanical interlocking, while porous structures may absorb adhesive components and reduce the effective bond area (Peressadko & Gorb, 2004). The highest mean separation mass observed in *H. rufipes* (63.2 g) compared to *L. rufomarginatus* (24.2 g) may reflect differences in body size and correspondingly larger adhesive contact area, or species-specific differences in epicuticular wax composition. The improvement in adhesion following light abrasion confirms the importance of surface preparation in overcoming wax-mediated adhesion failure. Insect epicuticular waxes are predominantly formed from long-chain hydrocarbons (C22–C35), fatty acids and methyl-branched alkanes to create hydrophobic, low-energy surfaces that resist wetting by both aqueous and non-polar adhesives (Howard & Blomquist, 2005). By removing or disrupting this wax layer, abrasion exposes the underlying cuticulin layer with higher surface energy and greater potential for adhesive bonding. However, abrasion must be calibrated carefully as excessive removal risks damaging the cuticle's structural integrity and compromising the insect's desiccation resistance (Gibbs 1998). Our protocol using 600-grit sandpaper (3–4 gentle strokes) appeared to achieve this balance, though future studies should quantify the relationship between abrasion intensity, wax removal and welfare outcomes. When applying surface abrasion to live beetles, individuals should be briefly immobilised by chilling at 4°C for 5–10 min to minimise stress and movement during the procedure. Surface cleaning with a damp cloth and mild detergent prior to adhesive application may also further improve adhesion by removing surface contaminants and oils, though this was not tested in the present study.

Although this study focused on mechanical bond strength, welfare implications of adhesive choice warrant consideration. Cyanoacrylates cure exothermically and release irritant vapours (formaldehyde and cyanoacetate), which could cause localised tissue damage or respiratory stress if applied near spiracles (Batsleer et al., 2020). Low-viscosity formulations pose risks due to their tendency to spread via capillary action into body crevices. Two-part epoxy cures more slowly with minimal exothermic reaction, potentially reducing acute stress during application. However, the extended handling time required for epoxy application may itself constitute a welfare cost. Future studies should quantify physiological stress responses (e.g. haemolymph metabolite levels, ventilation rates) across adhesive types to inform ethical best practice. The trade-off between abrasion-enhanced adhesion and potential welfare costs from cuticle damage also merits investigation; while our gentle sanding protocol improved the strength of tag adhesion, the long-term consequences for beetle survival and desiccation resistance remain unknown. Several limitations should be acknowledged. First, we measured adhesive performance at a single time point (24-h post-application); bond strength may change over longer periods as adhesives age, degrade, or interact with cuticular secretions. Field studies typically require tag retention for days to weeks, and longitudinal testing would better characterise adhesive durability. Second, our tensile separation test applied force perpendicular to the elytra, whereas beetles in the field experience complex shearing and torsional forces during movement through soil and vegetation. Additionally, tag dimensions and edge profile may interfere with typical carabid behaviours such as burrowing into soil or pushing through leaf litter; future studies should evaluate whether tag shape affects movement through confined spaces. Third, sample sizes for some adhesive × species combinations were limited, reducing power to detect interaction effects. Finally, we did not assess the ease of tag removal post-study, which is relevant for minimising handling stress during recapture. Future research should examine adhesive performance under simulated field conditions, assess long-term tag retention through mark-recapture studies, and evaluate non-invasive tag removal methods.

CONCLUSION

Effective RFID tracking of ground beetles requires reliable tag retention without compromising natural behaviour. Our study demonstrates that adhesive selection and surface preparation critically determine the strength of tag adhesion, with a two-part epoxy combined with light elytra abrasion providing optimal performance. The combination provides a reliable method for RFID tag attachment to carabid beetles, supporting future movement ecology studies. These findings provide a methodological foundation for expanding RFID applications in ground beetle research, ultimately contributing to an improved understanding of carabid movement ecology and the ecosystem services these beneficial predators provide in agricultural landscapes.

AUTHOR CONTRIBUTIONS

Leona Breen: Data curation; investigation; methodology; writing – original draft; writing – review and editing. **Joe M. Roberts:** Conceptualisation; data curation; formal analysis; methodology; visualisation; writing – original draft; writing – review and editing. **Tom W. Pope:** Conceptualisation; methodology; writing – original draft; writing – review and editing; supervision.

ACKNOWLEDGEMENTS

The authors are grateful to the Future Farm at Harper Adams University for access to field sites and to Nikoletta Foskolou for providing technical support.

FUNDING INFORMATION

No funding was secured in order to complete this research.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data used in this manuscript are openly available from the associated Figshare Data Repository at https://doi.org/10.6084/m9.figshare.30896429 (Pope, 2025).

ORCID

Joe M. Roberts https://orcid.org/0000-0002-9576-9239

Tom W. Pope https://orcid.org/0000-0002-3678-2943

REFERENCES

Allema, B., van der Werf, W., van Lenteren, J.C., Hemerik, L. & Rossing, W.A.H. (2014) Movement behaviour of the carabid beetle *Pterostichus melanarius* in crops and at a habitat interface explains patterns of population redistribution in the field. *PLoS One*, 9(12), e115751.

Baars, M.A. (1979) Catches in pitfall traps in relation to mean densities of carabid beetles. *Oecologia*, 41(1), 25–46.

Barlow, S.E., O'Neill, M.A. & Pavlik, B.M. (2019) A prototype RFID tag for detecting bumblebee visitations within fragmented landscapes. *Journal of Biological Engineering*, 13(1), 13.

Batsleer, F., Bonte, D., Dekeukeleire, D., Goossens, S., Poelmans, W., van der Cruyssen, E. et al. (2020) The neglected impact of tracking devices on terrestrial arthropods. *Methods in Ecology and Evolution*, 11(3), 350–361.

Bauer, L.J. (1989) Moorland beetle communities on limestone 'habitat islands'. I. Isolation, invasion and local species diversity in carabids and staphylinids. *The Journal of Animal Ecology*, 58(3), 1077.

Blight, O., Geslin, B., Mottet, L. & Albert, C.H. (2023) Potential of RFID telemetry for monitoring ground-dwelling beetle movements: a Mediterranean dry grassland study. *Frontiers in Ecology and Evolution*, 11, 1040931. Available from: https://doi.org/10.3389/fevo.2023.1040931

Boiteau, G., Meloche, F., Vincent, C. & Leskey, T.C. (2009) Effectiveness of glues used for harmonic radar tag attachment and impact on survival and behavior of three insect pests. *Environmental Entomology*, 38(1), 168–175.

Fernández, P., Rodríguez, A., Obregón, R., de Haro, S., Jordano, D. & Fernández-Haeger, J. (2016) Fine scale movements of the butterfly *Plebejus argus* in a heterogeneous natural landscape as revealed by GPS tracking. *Journal of Insect Behavior*, 29(1), 80–98.

Fox, J. & Weisberg, S. (2019) *An R companion to applied regression*. Thousand Oaks, CA: Sage.

Gibbs, A.G. (1998) Water-proofing properties of cuticular lipids. *American Zoologist*, 38(3), 471–482. Available from: https://doi.org/10.1093/icb/38.3.471

Gorb, S.N. (2008) Biological attachment devices: exploring nature's diversity for biomimetics. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, 366(1870), 1557–1574.

Howard, R.W. & Blomquist, G.J. (2005) Ecological, behavioral, and biochemical aspects of insect hydrocarbons. *Annual Review of Entomology*, 50(1), 371–393.

Kaláb, O., Musiolek, D., Rusnok, P., Hurtik, P., Tomis, M. & Kočárek, P. (2021) Estimating the effect of tracking tag weight on insect movement using video analysis: a case study with a flightless orthopteran. *PLoS One*, 16(7), e0255117.

Kinloch, A.J. & Hunston, D.L. (1987) Effect of volume fraction of dispersed rubbery phase on the toughness of rubber-toughened epoxy polymers. *Journal of Materials Science Letters*, 6(2), 137–139.

Kissling, D.W., Pattemore, D.E. & Hagen, M. (2014) Challenges and prospects in the telemetry of insects. *Biological Reviews of the Cambridge Philosophical Society*, 89(3), 511–530.

Kromp, B. (1999) Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. *Agriculture, Ecosystems & Environment*, 74(1–3), 187–228.

Kulkarni, S.S., Dosdall, L.M. & Willenborg, C.J. (2015) The role of ground beetles (Coleoptera: Carabidae) in weed seed consumption: a review. *Weed Science*, 63(2), 355–376.

Lee, D.-H., Wright, S.E., Boiteau, G., Vincent, C. & Leskey, T.C. (2013) Effectiveness of glues for harmonic radar tag attachment on *Halyomorpha halys* (Hemiptera: Pentatomidae) and their impact on adult survivorship and mobility. *Environmental Entomology*, 42(3), 515–523.

Lenth, R. & Piaskowski, J. (2025) emmeans: estimated marginal means, aka least-squares means. Available from: https://rvlenth.github.io/emmeans/ [Accessed 24th January 2026].

Lindroth, C.H. (1974) On the *Elytral microsculpture* of carabid beetles (Col. Carabidae). *Insect Systematics & Evolution*, 5(3–4), 251–264.

Lövei, G.L. & Sunderland, K.D. (1996) Ecology and behavior of ground beetles (Coleoptera: Carabidae). *Annual Review of Entomology*, 41(1), 231–256.

Luff, M.L. & Rushton, S.P. (1989) The ground beetle and spider fauna of managed and unimproved upland pasture. *Agriculture, Ecosystems & Environment*, 25(2–3), 195–205.

Osborne, J.L., Williams, I.H., Carreck, N.L., Poppy, G.M., Riley, J.R., Smith, A.D. et al. (1997) Harmonic radar: a new technique for investigating bumblebee and honey bee foraging flight. *Acta Horticulturae*, 437, 159–164.

Peressadko, A. & Gorb, S.N. (2004) When less is more: experimental evidence for tenacity enhancement by division of contact area. *The Journal of Adhesion*, 80(4), 247–261.

Pope, T. (2025) Data for Breen et al. (2026) Evaluating the efficacy of tagging adhesives for insect tracking. Available from: https://doi.org/10.6084/m9.figshare.30896429

R Core Team. (2024) *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Available from: https://www.R-project.org/

Růžičková, J. & Elek, Z. (2023) Beetles on the move: not-just-a-technical review of beetles' radio-tracking. *Entomologia Experimentalis et Applicata*, 171(2), 82–93.

Růžičková, J. & Veselý, M. (2016) Using radio telemetry to track ground beetles: movement of *Carabus ullrichii*. *Biologia*, 71(8), 924–930.

Spence, J.R. & Niemelä, J.K. (1994) Sampling carabid assemblages with pitfall traps: the madness and the method. *The Canadian Entomologist*, 126(3), 881–894.

Streit, S., Bock, F., Pirk, C.W.W. & Tautz, J. (2003) Automatic life-long monitoring of individual insect behaviour now possible. *Zoology (Jena, Germany)*, 106(3), 169–171.

Symondson, W.O.C., Sunderland, K.D. & Greenstone, M.H. (2002) Can generalist predators be effective biocontrol agents? *Annual Review of Entomology*, 47(1), 561–594.

Vincent, J.F.V. & Wegst, U.G.K. (2004) Design and mechanical properties of insect cuticle. *Arthropod Structure & Development*, 33(3), 187–199.

Voigt, D. & Gorb, S. (2008) An insect trap as habitat: cohesion-failure mechanism prevents adhesion of *Pameridea roridulae* bugs to the sticky surface of the plant *Roridula gorgonias*. *Journal of Experimental Biology*, 211(Pt 16), 2647–2657.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R. et al. (2019) Welcome to the tidyverse. *Journal of Open Source Software*, 4(43), 1686.

How to cite this article: Breen, L.C.R., Roberts, J.M. & Pope, T. W. (2026) Evaluating the efficacy of tagging adhesives for insect tracking. *Agricultural and Forest Entomology*, 1–7. Available from: https://doi.org/10.1111/afe.70047