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Ranunculus trilobus Desf. (Ranunculaceae), a newly naturalised species in Aotearoa / New Zealand

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Abstract

The Mediterranean species *Ranunculus trilobus* Desf. (Ranunculaceae) is reported here for the first time as naturalised in Aotearoa / New Zealand. The new exotic was initially reported on the citizen science network iNaturalist during a COVID-19 lockdown in Tāmaki Makaurau / Auckland (1 September–15 December 2021). Since then, additional records have been confirmed from other localities in Tāmaki Makaurau / Auckland and Te Tai Tokerau / Northland. *Ranunculus trilobus* is illustrated here, and a key is provided to distinguish it from other exotic *Ranunculus* species present in Aotearoa / New Zealand. This discovery highlights the important role both community science and herbaria can play in biodiversity research, and how COVID-19 lockdowns indirectly contributed to botanical discoveries.

Keywords

Citizen science, COVID-19, invasive species, Ranunculaceae, *Ranunculus*, *R. trilobus*, Aotearoa / New Zealand flora

Introduction

The global reduction in human activity and movement during the COVID-19 pandemic, the period that has been referred to as the 'anthropause', provided a unique opportunity to observe biodiversity patterns with reduced anthropogenic disturbance. This period was marked by a notable increase in the volume and spatial extent of biodiversity observations submitted through citizen science platforms such as iNaturalist (https://www.inaturalist.org/) (Drill et al. 2022; Rutz et al. 2020). This data contributed to the detection of novel species occurrences, range extensions and, in some cases, species new to science. It was no different here in Aotearoa / New Zealand.

In October 2020 the English-born Tāmaki Makaurau / Auckland-based entomologist Stephen Thorpe posted on iNaturalist an observation of an unknown *Ranunculus* (https://inaturalist.nz/observations/61359793) found in central Tāmaki Makaurau / Auckland (Te Ika-a-Māui / North Island). Unfortunately, the observation did not illustrate enough morphological details to confirm its identification to the species level. Thorpe found this entity at multiple locations around the urban Tāmaki Makaurau area and created a tag name on iNaturalist for it: "*Ranunculus* sp. ST1". It was not until 2021, when the September COVID-19 lockdown took place, that the lead author of this article found another population of the same entity, but in West Auckland, on a road verge in New Lynn (Figures 1–3) (https://inaturalist.nz/observations/95239432). This observation included photographs of many structures of taxonomic value and confirmed this entity did not match any *Ranunculus* previously recorded in Aotearoa / New Zealand. By October 2021, the second author of this paper suggested that Thorpe's *Ranunculus* sp. ST1 could be *Ranunculus trilobus* Desf., a species not previously recorded here. Almost a year later (7 August 2022), Thorpe found another population of this *Ranunculus*, this time from Blockhouse Bay in West Auckland.

Ranunculus L. (Ranunculaceae) is a genus of annual and perennial herbs. It is the largest genus of the family, with c. 600 species distributed through in Australasia, Europe, North America and South America (Tamura 1995). Members of the genus occur in a range of habitats including forests, dry and damp meadows, marshes, puddles and streams, shallow and marshy banks of rivers and lakes, and the alpine zone (Fisher 1965). Aotearoa / New Zealand is particularly diverse in *Ranunculus* with 44 species currently recognised (Allan Herbarium 2025), many of them endemic. In total, 12 exotic species are considered naturalised nationally (Allan Herbarium 2025); none of these matched this new find. Previous local treatments by Garnock-Jones (1988) also included *Ranunculus ficaria* L., which has since been transferred to the genus *Ficaria* Guett. and is not treated here.

Here, we formally confirm and document the occurrence of *Ranunculus trilobus*, an exotic buttercup species, in Aotearoa / New Zealand; a discovery made possible through iNaturalist during a period of

Figure 1. Habitat of *Ranunculus trilobus* Desf. growing along a road verge in Blockhouse Bay, West Auckland. Photo: Marley Ford, 8 August 2022. Voucher specimens of this population are deposited at AK, *M. Ford 1255*, AK 387892.

Figure 2. Habitat of *Ranunculus trilobus* Desf. growing along a road verge in New Lynn, West Auckland. Photo: Marley Ford, 18 September 2021. Voucher specimens of this population are deposited at WELT, specimens *M. Ford 805*, SP122916 A-C.

Figure 3. Detailed view of vegetative and reproductive structures of *Ranunculus trilobus* Desf. growing along a road verge in New Lynn, West Auckland. **A.** Stem leaf; **B.** Flower; **C.** Sepals (arrow); **D.** Achenes. Scale bar = 2 cm. Photos: Marley Ford, 18 September 2021. Voucher specimens of this material are deposited at WELT, specimens *M. Ford 805*, SP122916 A-C.

heightened citizen-science engagement. Also, to help with its identification and monitor the spread of this weedy species, we provide a revised key to identify exotic species of *Ranunculus* and a map showing its current known distribution.

Methods

Sample collection and identification

Samples were collected from two sites in Tāmaki Makaurau / Auckland (i.e., New Lynn and Blockhouse Bay in West Auckland) and voucher specimens were prepared and lodged at the Auckland War Memorial Museum Herbarium (AK), the Museum of New Zealand Te Papa Tongarewa Herbarium (WELT) and the Otago Regional Herbarium (OTA). Collected specimens were compared against the *Ranunculus* collections stored at the main national herbaria: AK, WELT and the Allan Herbarium (CHR), type specimens via JSTOR Global Plants (https://plants.jstor.org/) and the Chinese Virtual Herbarium (https://www.cvh.ac.cn/). Time constraints meant that *Ranunculus* collections were examined more thoroughly at some herbaria than at others. Specifically,

Figure 4. Distribution map of *Ranunculus trilobus* in Aotearoa / New Zealand, based on herbarium specimen records and redeterminations (yellow) and iNaturalist observations (blue). The larger map shows the distribution in the Tāmaki Makaurau / Auckland region, while the inset map shows the broader distribution in northern Aotearoa / New Zealand. Map created using QGIS Desktop 3.34.13 with Esri World Imagery basemap.

all specimens at WELT and OTA were studied, while those at AK and CHR were not comprehensively examined. A full list of the specimens examined for this paper can be obtained from the corresponding author. Identification of this *Ranunculus* was also assisted by using the identification key for *Ranunculus* in Aotearoa / New Zealand by Garnock-Jones (1988) and the New South Wales Online Flora key (PlantNET n.d.).

Additionally, 17 observations tagged as "*Ranunculus* sp. ST1" posted on iNaturalist (www.inaturalist.nz, accessed 26 June 2023) were studied to further confirm their identification. A distribution map for the species was prepared based on data from herbarium specimens and records posted on iNaturalist (Figure 4).

DNA extraction and sequencing

A leaf fragment from a specimen collected at Blockhouse Bay (voucher WELT SP122915, GenBank PX556453) was dissected and used for DNA analyses. Leaf tissue was finely crushed using a TissueLyser II machine (QIAGEN) and DNA extracted following Doyle and Doyle's (1987) CTAB protocol. The internal transcribed spacer (ITS) was amplified using the primers of Baldwin (1992). Polymerase chain reactions (PCRs) were performed in a total volume of 20 µL that consisted of 1 µL of DNA, 4 µL of betaine (5 M), 2.5 µL of dNTPs (2 mM), 2 µL 10× of buffer (Roche), 1 µL of each primer (10 nM), 0.2 µL of Taq (1 U, Roche) and 8.3 µL of water. PCRs were performed on a T1 thermocycler (Biometra), and thermocycling conditions for ITS and plastid regions followed White et al. (1990). PCR products were purified using 2 µL Sap (2 U) and 1 µL Exo I (1 U), both from GE HealthCare Life Sciences, and sequenced in both directions using ABI PRISM BigDye Terminator Cycle Sequencing Ready Reaction Kits (Applied Biosystems) and run on a 3730 Series Genetic Analyzer (Applied Biosystems) at Massey University Genome Service (Te Papaioea / Palmerston North). Consensus sequences were created from forward and reverse sequences using Geneious 5.6.5 (Biomatters), and BLAST searches on GenBank were performed to confirm identification and closest relatives. This sequence is included with this paper as a supplementary file and was submitted to GenBank on 4 November 2025 (PX556453) (National Library of Medicine n.d.).

Results

The morphological and comparative study of the specimens we collected confirmed they belong to *Ranunculus trilobus*. The same result was obtained after using the *Ranunculus* key from the New South Wales Online Flora key, and our identification was further confirmed by Dr Rhys Gardner, who redetermined a specimen (*M.Ford 805*, AK 387892!) as *R. trilobus*.

The achenes of *R. trilobus* bear short, blunt tubercles on their lateral faces, a feature that helps to distinguish it from any other Aotearoa / New Zealand native *Ranunculus*, and groups it with members of sect. *Echinella* DC. which have achenes with small tubercles, spines or recurved trichomes (Keener & Hoot 1987) (see Figures 5 and 6). From other members of this section occurring locally, *R. trilobus* is further separated by the size of its flowers (9–14 mm diameter), its leaves being divided into three separate stalked leaflets, and the presence of tubercules instead of spines or recurved trichomes as occur in *R. arvensis* L., *R. muricatus* L., *R. parviflorus* Loefl. or *R. sessiliflorus* R.Br. ex DC. (Figures 5 and 6). The achene shape and surface sculpture of *R. trilobus* are closest to *R. sardous* Crantz, but it can be distinguished from it by the distribution of tubercles, which are scattered all over the achene's face in *R. trilobus*, rather than restricted to the margins as in *R. sardous* (Figure 5). Furthermore, the leaves of *R. trilobus* differ by being more lobed and less overlapping than those of *R. sardous*, and the latter is hirsute while *R. trilobus* has few scattered villous hairs. *R. sardous* is one of the most common buttercup species in northern Aotearoa / New Zealand, so care needs to be taken to separate this species from *R. trilobus* in the field, because the tubercules are not always obvious on the former species.

Ranunculus trilobus is vegetatively similar to the three-lobed ranunculi *R. reflexus* Garn.-Jones, *R. urvilleanus* Cheeseman and *R. repens* L. In *R. trilobus* the young basal leaves are ovate–cordate, becoming trilobed as they mature. It can be distinguished from the other species by its more sharply angled lobes and straight-edged margins, which lack the rounded serrations typical of the other species (Figure 3). The hairs on the leaves of *R. trilobus* are pubescent and much sparser than those on the other species. *R. repens* further differs from the other species by the creeping habit. Additionally, the tubercules on the achenes of *R. trilobus* provide a key diagnostic feature, separating it from the other species with three-lobed leaves mentioned above. The species

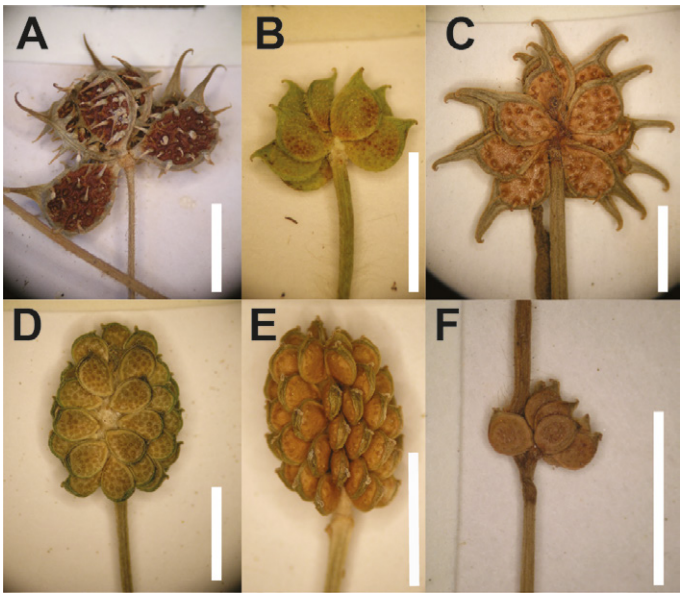

Figure 5. Six exotic species of *Ranunculus* found in Aotearoa / New Zealand in which achenes have spines, hooks or tubercles. **A.** *R. arvensis* (*S. Fultons s.n.*, WELT SP123463); **B.** *R. parviflorus* (*B.Sneddon s.n.*, WELT SP105206); **C.** *R. muricatus* (*W. L. Williams s.n.*, WELT SP062002); **D.** *R. trilobus* (*M. Ford 1255*, WELT SP122915); **E.** *R. sardous* (*E. Bangerter s.n.*, WELT SP070521), **F.** *R. sessiliflorus* (*T. Kirk s.n.*, WELT SP026394). Scale bar = 5 mm.

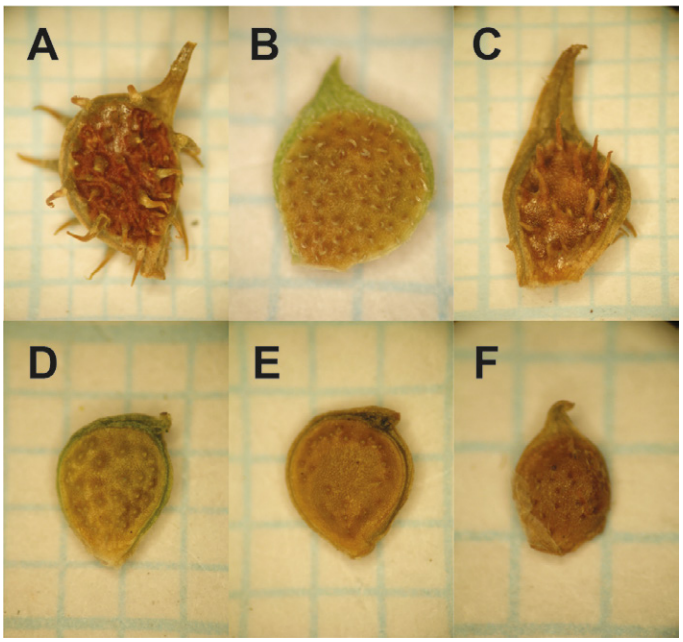

Figure 6. Close-up view of the achene body of: **A.** *R. arvensis* (S. Fultons s.n., WELT SP123463); **B.** *R. parviflorus* ((*B. Sneddon s.n.*, WELT SP105206); **C.** *R. muricatus* (*W. L. Williams s.n.*, WELT SP062002); **D.** *R. trilobus* (*M. Ford 1255*, WELT SP122915); **E.** *R. sardous* (*E. Bangerter s.n.*, WELT SP070521); **F.** (*T. Kirk s.n.*, WELT SP026394). Grid on background graph paper is 1 mm.

R. bulbosus L. is uncommon in Aotearoa / New Zealand and can be separated from *R. trilobus* by the smooth achenes.

An outlier specimen of *R. trilobus* (*A. E. Wright 9580*, AK 215480) from Te Aupōuri in Te Tai Tokerau / Northland, collected on Far North Road approximately 1.2 km south of Houhora (Figure 4), has been identified during this study. To confirm the presence of *R. trilobus* in this part of Aotearoa / New Zealand, targeted field surveys are recommended to relocate this population.

Molecular identification

The ITS sequence generated was 603 bp long and, after blast searching it, the species with the highest similarity retrieved from GenBank were *R. trilobus* (identity: 99.50%; query cover: 99%; GenBank accession: AY680149.1) and *R. shuichengensis* L. Liao (identity: 99.34%; query cover: 100%; GenBank accession: JQ439579.1).

Taxonomy

***Ranunculus trilobus* Desf.**, *Fl. Atlant. 1: 437, t. 113* (1798)

Description (adapted from Lone et al. F. A. (2014)): Terrestrial herb, annual. Stem solitary or 2–3, erect, terete, branched, 10–49 cm high, 2.0–3.5 mm in diameter, hollow, continuously pubescent with long appressed or spreading trichomes. Basal leaves with petiole 3.5–14 cm long, sulcate along the upper side, continuously hairy with appressed trichomes; lamina cordate–ovate with cordate base, 4.5–9.5 × 4.0–9.0 cm, trifid, middle segment 3-partite or occasionally unequally 2-partite with 0.5–1.0 cm long petiolule, lateral segments 3-partite or irregularly lobed, lobule margins incised dentate, both surfaces pubescent, upper surface with scattered trichomes and lower surface with continuous trichomes, trichomes transparent, appressed; cauline leaves similar to basal ones, petioles shorter, 20–30 mm long. Flowers yellow, 9–14 mm across; pedicel 10–20 mm long, pubescent with appressed hairs. Sepals 5, ovate to obovate, reflexed, 3–3.75 × 1–15 mm, sparsely hairy on lower side. Petals 5, imbricate, ovate with rounded apex, 5–6 × 3–4 mm; nectary pit covered with 0.5–1 × 0.5–1 mm scale; claw 0.5–1 mm. Stamens 25–30, 3–4 mm long; filaments 1.75–2.5 mm; anthers adnate, 1.25–1.5 mm, latrorse. Carpels 25–35, 1–1.5 mm long, glabrous, minutely papillate in the ovary region.

Achenes flattened, 25–40 per head, orbicular–obovate, 2.5–3 × 1.75–2.25 mm; faces covered with short blunt tubercules, distinctly marginate, margin smooth; beak small, 0.5–1 mm. Torus club-shaped, 4–5.5 × 1.5–2 mm, sparsely hairy, trichomes 0.5–1 mm. Flowering and fruiting: July–December.

Distribution: Europe (native), Australia, North America, China, India, Aotearoa / New Zealand (Figure 4).

Specimens seen: TE IKA-A-MĀUI / NORTH ISLAND: Aupōuri: Houhora, *A. E. Wright s.n.*, 2 Dec 1989, AK 215480. Tāmaki Makaurau / Auckland: Waikumete Cemetery, *E. K. Cameron & A. E. Esler s.n.*, 9 Oct 1999, AK 241513; New Lynn, *M. Ford & K. Gilbride s.n.*, AK 384277 (duplicate WELT SP122916A-C); Blockhouse Bay, *M. Ford s.n.*, 8 Aug 2022, AK 387886; Blockhouse Bay, *M. Ford s.n.*, 8 Aug 2022, AK 387892 (duplicate WELT SP122915).

Taxonomic affinities: Phylogenetic studies by Hörandl et al. (2005) and Paun et al. (2005), based on nuclear and chloroplast sequence data, have suggested *R. trilobus* is closely related to Mediterranean species such as *R. muricatus*, *R. cornutus* DC. and *R. marginatus* d'Urv. These species are part of a clade that also includes *R. sardous*, which historically has been considered related to *R. trilobus* (Jauzein 1995) and *R. bulbosus*. The affinity of *R. trilobus* with *R. shuichengensis*, as detected by blasting the ITS sequence, however, was novel. *Ranunculus shuichengensis* is a Chinese species described almost 30 years ago (Liang & Ling-ling 1997). Material from this species was not included in Hörandl et al. (2005) or Paun et al. (2005), therefore, until a suitable multi-marker phylogenetic study is conducted, its affinities with *R. trilobus* will remain unknown. After studying the description and the holotype of *R. shuichengensis* at the China National Herbarium (PE), we are certain our specimens do not belong this species. One of the key characters supporting our decision is the smooth achenes of *R. shuichengensis* (see Figure 1 in Liang & Ling-ling 1997). Recently, *R. shuichengensis* has been synonymised with *R. trigonus* Hand.-Mazz. (see Scientific Data Curation Team 2021 [cited as *Ranunculus trigonus*]; Wencai & Gilbert 2001), a species distributed from Southeast Tibet to China (Fei et al. 2023). The achenes of *R. trigonus* are smooth (i.e., without tubercules), a characteristic that is stable across different localities, as is observable in photographs of fresh material included in Fei et al. (2023).

Ecology: Ephemeral annual herb of lightly mown lawns in clay or sandy soils, mesic to dryish, similar to that of *R. sardous*. Found on urban road verges (*M. Ford 805*, AK 387892) (Figure 1), graveyard lawns (*E. K. Cameron 9885*, AK 241513) and as a weed on sandy roadsides (*A. E. Wright 9580*, AK 215480). Found with a variety of other weeds, including *Allium triquetrum* L., *Anthemis cotula* L., *Bellis perennis* L., *Cenchrus clandestinus* Chiov., *Cerastium glomeratum* Thuill., *Cynodon dactylon* (L.) Pers., *Erigeron sumatrensis* Retz., *Eurhynchium praelongum* (Hedw.) Schimp., *Erodium moschatum* (L.) L'Hér., *Hypochaeris radicata* L., *Lotus pedunculatus* Cav., *Lysimachia arvensis* (L.) U.Manns & Anderb., *Plantago lanceolata* L., *Rumex L.* sp., *Sonchus oleraceus* L., *Trifolium pratense* L., *Trifolium repens* L., *Veronica persica* Poir., and *Festuca* sect. *Vulpia* (C.C. Gmel.) Endl. sp. (Figures 1 and 2).

For more photographs of habitat, see https://inaturalist.nz/observations/95239432, https://inaturalist.nz/observations/129932416, https://inaturalist.nz/observations/129932415.

Discussion

This new record of *Ranunculus trilobus* brings the total of naturalised *Ranunculus* species in Aotearoa / New Zealand to 13. *R. trilobus* is widely distributed throughout the world, thought to be native to the Mediterranean, and is widely naturalised in Australia, Europe, India, New Caledonia and North America. The epithet highlights the three-lobed leaves of the species; it has commonly been called three-lobed buttercup. It is part of the *Ranunculus* sect. *Echinella*, which can be distinguished from other sections by the sculpturing of the achene faces, and presence of small tubercles, spines or recurved trichomes (Keener & Hoot 1987).

In Aotearoa / New Zealand, *R. trilobus* appears to be a very localised annual weed, mostly found in urban environments, and it seems unlikely it will become a serious pest plant. Studies into the weedy buttercups of Tāmaki Makaurau / Auckland by Gardner (2015) did not report this species, suggesting it might be a recent local arrival or a species with a very localised distribution. It has been found in the wider region, with one outlier record in the Karikari Peninsula (Figure 4). The outlier specimen (*A. E. Wright 9580*, AK 215480) is the first record for Aotearoa / New Zealand, collected in Te

Aupouri, Te Tai Tokerau / Northland in 1989, found on a sandy roadside, and searches in the general area have failed to relocate this population; the second, a Tāmaki Makaurau / Auckland specimen, in 1999 (*E. K. Cameron 9885*, AK 241513); and the most recent in 2021 and 2022 (*M. Ford 805*, WELT SP122916 A-C,). iNaturalist Aotearoa / New Zealand observations date back to 2017 (https://inaturalist.nz/observations/7388832). The urban Tāmaki Makaurau / Auckland specimens have been found in roadside verges (*M. Ford 805*, AK 387892) (Figures 1 and 2) and graveyard lawns (*E. K. Cameron 9885*, AK 241513). The urban locations in which this species has been found suggest it is a recent naturalisation, potentially brought in as a contaminant.

In the Mediterranean, *R. trilobus* is typically associated with mesic habitats and is regarded as a hygrophilous species requiring substantial moisture for germination (Brullo et al. 2022). Locally, however, its occurrence in sandy soils and on roadside verges suggests no affinity for wet environments, likely reflecting the moist conditions of the temperate climate of Aotearoa / New Zealand (Salinger & Mullan 1999). *R. trilobus* has been noted as sometimes invasive in pasture (VicFlora Flora of Victoria n.d.), and although most Aotearoa / New Zealand records are from urban environments, the species has the potential to become more widespread, like the invasive *R. sardous*, which is locally abundant in agricultural areas (Esler, 1988). If *R. trilobus* enters farmed areas with increased vectors for seed dispersal, it could become a locally invasive weed. *R. trilobus* has high reproductive potential, and on average, a plant produces 475 seeds on 8–15 fruit heads throughout its annual cycle; the seeds also have a high percentage of germination at 85 to 94.5% (Lone et al. 2014). The tubercules on the achene surface can facilitate dispersal by attachment to the hairs of cattle (*Bos taurus* Linnaeus, 1758) and sheep (*Ovis aries* Linnaeus, 1758), which are more common in agricultural areas; and wind dispersal is also a possibility (Lone et al. 2014).

The discovery of *R. trilobus* in Aotearoa / New Zealand was facilitated through iNaturalist during a period of heightened citizen science engagement. This finding was further enhanced by tracing herbarium specimens, which showed that the species had been recorded 28 years (*A. E. Wright 9580*, AK 215480) and 18 years (*E. K. Cameron 9885*, AK 241513) prior to the first iNaturalist observation (https://inaturalist.nz/observations/7388832).

Key to *Ranunculus* naturalised in Aotearoa / New Zealand, adapted from Garnock-Jones (1988) and Keener & Hoot (1987)

1. Petals white with yellow claw; leaves divided into filiform segments.....*R. trichophyllus*

Petals yellow; leaves not divided or segments linear to broadly obovate.....*2.*

2. Achenes tuberculate to spiny on faces.....*3.*

Achenes smooth on faces.....*9.*

3. Achenes 3–7 × 2.5–5.0 mm; face of achene with strong long curved spines especially near margins.....*4.*

Achenes 1.5–3.0 × 1.0-3.0 mm; face of achene with short weak hooked spines or blunt tubercles.....*5.*

4. Sepals spreading at flowering; achenes 5–8 mm long.....*R. arvensis*

Sepals deflexed at apex; achenes 15–25 mm long..... .....*R. muricatus*

5. Lamina of stem leaves linear to lanceolate, cuneate, simple, never lobed, weakly toothed, with closely appressed hairs or glabrous.....*R. ophioglossifolius*

Lamina of stem leaves ovate to ± circular, truncate to cordate at base, divided to at least half-way and crenate or toothed, with erecto-patent to spreading hairs.....6.

6. Flowers > 8 mm diameter; leaves vs divided into 3 separate stalked leaflets; achenes tuberculate near margin.....*7.*

Flowers < 6 mm diameter; leaves 3–5-lobed to c. half-way; achenes with short, hooked spines.....*8.*

7. Achene discs sparsely protuberant to smooth; petals more than 5 mm long; plants more or less hirsute..... .....*R. sardous*

Achene discs with numerous short spines; petals less than 5 mm long; plants with a few scattered villous hairs.....*R. trilobus*

8. Flowers and fruits sessile or on peduncles < 5 mm

long; achenes (1–)3(–6), 1.5–2.0 × 1.0–1.3 mm.....*R. sessiliflorus*

Flowers and fruits on peduncles 8–40 mm long; achenes (5–)10(–20), 2.0–2.5 × c. 2 mm.....*R. parviflorus*

9. Leaves divided into 3 separate leaflets; leaflets stalked, the middle one on a longer stalk than the 2 lateral ones.....*10.*

Leaves not divided, or else 3–7-lobed sometimes to base of lamina; leaflets never stalked.....*11.*

10. Stems creeping, rooting at nodes; rootstock ± slender; sepals spreading.....*R. repens*

Stems erect, not rooting at nodes; rootstock bulbous; sepals reflexed.....*R. bulbosus*

11. Leaves 3–7-lobed to half-way or more.....*12.*

Leaves not divided, the margin crenate or shallowly toothed.....*R. flammula*

12. Sepals reflexed; leaves glabrous; achenes c. 1 mm long, in cylindric heads of 100–700.....*R. sceleratus*

Sepals spreading; leaves hairy; achenes 2.5–3.5 mm long, in globose heads of 30–60.....*R. acris*

Data Accessibility Statement

No additional database.

Author Contributions

Marley Ford: Conceptualisation (lead); investigation (lead); project administration (lead); supervision (lead); data curation (lead); validation (lead); writing – original draft preparation (lead); writing – review and editing (lead); figures (lead).
William Reinders: Data curation (equal).
Carlos A. Lehnebach: Investigation (equal); validation (equal); writing – review and editing (equal); figures (equal); resources (equal).

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