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## A new pygmy sundew, *Drosera albonotata* (Droseraceae), from the western Wheatbelt and an updated diagnostic key to the orange-flowered pygmy *Drosera* of Western Australia

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### Abstract

A new species of *Drosera*—*Drosera albonotata*—from the western Wheatbelt (Western Australia) is described and illustrated. The taxon, which is largely restricted to sandy clay loam soils in Wandoo woodland and shrubland, is morphologically similar to *D. miniata* and *D. coomallo* but can be distinguished by its distinct floral features and ecology. A distribution map of the new species and its allies and a revised and updated diagnostic key to the twelve recognised orange-flowered pygmy *Drosera* in Western Australia are provided.

**Keywords:** Australia, carnivorous plants, Droseraceae, *Drosera* section *Bryastrum*, non-core Caryophyllales, Taxonomy

### Introduction

*Drosera* Linnaeus (1753: 281) (Droseraceae Salisb., non-core Caryophyllales (APG IV 2016)) is a genus of herbaceous carnivorous plants and the largest carnivorous plant genus in the world, with a cosmopolitan distribution of approximately 250 species, of which *ca.* 110 are endemic to SW Australia alone (APG IV 2016, Robinson *et al.* 2017, Fleischmann *et al.* 2018). The majority of *Drosera* species are hemicyptophytic perennials that produce inflorescences in the form of simple scorpioid cymes (Diels 1906, Robinson *et al.* 2017, Fleischmann *et al.* 2018). Four monophyletic subgenera are currently accepted in *Drosera* (Fleischmann *et al.* 2018), of which the Australian *Drosera* subgenus *Ergaleium* (Candolle 1824: 319) Drude (1888: 271) is the largest one and the most diverse in terms of plant form and species number (see Fleischmann *et al.* 2018; this is the “Australian clade” of Rivadavia *et al.* 2003, 2012), and which includes the pygmy, tuberous and woolly sundews.

The highest rates of endemism in *Drosera* occur in oligotrophic Mediterranean (seasonally arid) ecosystems (Yesson & Culham 2006, Fleischmann *et al.* 2018). Rates of alpha-diversity are particularly high in the quartzitic *campos rupestres* montane scrublands of Brazil, the sandstone-associated *fyngbos* of South Africa, the tropical to subtropical scrublands of northern Australia and the Kwongan scrublands of Western Australia (Lambers 2014, Robinson *et al.* 2017, Fleischmann *et al.* 2018). *Drosera* subgenus *Ergaleium* sect. *Bryastrum* Planchon (1848: 94) diversified in the latter region. Commonly known as pygmy sundews, this group of relatively dwarf, rosetted species is characterised by (1) greatly expanded stipules, which form a protective stipule bud in the centre of the rosette which, in most pygmies, is vital to surviving the dry summer season; and (2) the ability to reproduce asexually through the production of gemmae (bulbils formed from modified leaves; Goebel 1908), with the notable exception of *D. meristocaulis*, an isolated species of *D.* sect. *Bryastrum* in South America (Rivadavia *et al.* 2012). A significant proportion of pygmy *Drosera* also produce rapidly moving unifacial marginal glands (Poppinga *et al.* 2012), particularly Type I glands (mucilage producing, symmetrical glandular heads positioned on relatively fast-moving, greatly elongated marginal stalks with very broad bases; for terminology, see e.g. Poppinga *et al.* 2012). However, Type II glands (bisymmetrical, non-glandular, trowel-like heads flattened on the abaxial side and adaxially convex, borne on very fast-moving marginal stalks) are also documented in dozens of species (Lowrie *et al.* 2017).

At least four groups of species can be distinguished in *Drosera* sect. *Bryastrum* based on morphology of gemmae, the characteristics of which are fairly stable within a given species (Lowrie 1989, 2014). However, pygmy *Drosera* species that are not closely related can sometimes be mistakenly grouped together based on other characteristics (e.g. flower colour), which can be misleading. The orange-flowered pygmy sundews of southwest Western Australia are one such group; eleven different species occur in this region that produce only orange-petalled blooms or, in one case, a range of petal colours that may include orange. These include *D. barbiger*a Planchon (1848: 287), *D. pulchella* Lehmann (1844: 38) with various flower colours including orange, *D. platystigma* Lehmann (1844: 37), *D. hyperostigma* Marchant & Lowrie (1992: 324), *D. sewelliae* Diels in Diels & Pritzel (1904: 206), *D. leucoblasta* Bentham (1864: 458), *D. echinoblastus* Marchant & Lowrie (1992: 322), *D. callistos* Marchant & Lowrie (1992: 321), *D. bindoon* Lowrie (2014: 1269), *D. coomallo* Lowrie (2014: 1269) and *D. miniata* Diels in Diels & Pritzel (1904: 206).

Two of these orange-flowered species, *Drosera miniata* and *D. coomallo*, along with *D. walyunga* Marchant & Lowrie (1992: 328) which may have white, pink or rarely salmon coloured flowers, form a natural group based on shared characteristics that include the shape of their gemmae, which are laterally compressed with an upper dorsal bulge and large growth point; their pedicels, which are reflexed (pendulous) in fruit; and their stipules, which have serrate lateral margins. This relatedness is confirmed by phylogenetic data (A. Fleischmann, unpubl. data) as well as extensive hybridisation studies performed on plants in cultivation, which have shown that *D. miniata* and the new taxon described in the present paper can readily hybridise with *D. walyunga* (M. Meisterl, pers. observ.). The production of flowers with orange petals and a dark centre is evidently a polyphyletic character in *D.* sect. *Bryastrum*. For example, *D. barbiger*a belongs in a clade that includes *D. scorpioides* Planchon (1848: 288) and *D. silvicola* Lowrie & Carlquist (1992: 105), as evidenced from morphology and confirmed by phylogeny (Rivadavia *et al.* 2012).

*Drosera coomallo* was separated from *D. miniata* by Lowrie (2014) based primarily on its densely glandular inflorescence, elliptic sepals with irregularly indented margins and its obovate petals. It also occurs *ca.* 100 km north of all known *D. miniata* locations (Lowrie *et al.* 2017). Observations of *D. miniata* material from a variety of locations have indicated that *D. miniata* (*sensu* Lowrie 1989, 2014) might include an additional taxon, prompting comparative observations of wild and cultivated material, along with studies of herbarium specimens. It was found that a proportion of *D. miniata* records do indeed comprise plants that are distinguishable from *D. miniata* (*sensu* Diels 1904, 1906) by differences in floral characteristics and ecology, which are significant characters for taxonomic delimitation in *D.* sect. *Bryastrum* (Lowrie 1989, 2014; Lowrie *et al.* 2017). Though *D. barbiger*a, *D. callistos* and *D. hyperostigma* have been recorded in adjacent habitats in the west of its range, populations of the taxon newly described here as *Drosera albonotata* are mostly isolated from other pygmy *Drosera* species. Moreover, its characteristics remain stable between populations (and in cultivation, as compared to *D. miniata*) despite being dispersed across a broad, if highly fragmented, range. The taxon is herein separated from *D. miniata*, its closest relative in terms of flower morphology, scape indumentum and geography.

## Materials & Methods

Plant populations of *Drosera albonotata* and related taxa were studied *in situ* in Western Australia in 2008, 2013, 2014 and 2017. Measurements were made using a Leica M125C microscope with an LAS Multifocus module (Leica Microsystems Fremont, CA, USA) and a Mitutoyo vernier caliper (Mitutoyo Corporation, Japan) and taken from field collected material (ASR and ATC) subsequently deposited at PERTH (collected under license SW017966), from herbarium specimens (ASR and AF) housed in B, M and PERTH (herbarium acronyms follow Thiers 2018+), and from cultivated plants (MEM and AF) grown from material purchased from Allen Lowrie.

Petal ratios were calculated from three different width measurements, A, B and C (see Discussion) made across the petals of sample materials. Lengthwise measurements were not used as these were found to vary considerably even within individual populations of a given species. Ratios were established by dividing A by B and A by C. Two-sample *t*-tests were used to test for a significant difference between the ratios of A/B and A/C. Statistical analyses were calculated using RStudio (version 1.0.153, MacOS High Sierra 10.13) to assess assumptions of normality, homogeneity of variance and statistical significance of observed morphometric values in petal shape.

All *de novo* georeferencing was made using a Garmin Oregon 600 GPS unit with dual GPS and GLONASS telemetry enabled. Measurements were made with a minimum of 5 averaged waypoint readings over the course of a 30-minute period, with an estimated accuracy of +/- 2 m.

Seeds of *Drosera albonotata*, *D. coomallo* and *D. miniata* were harvested from cultivated plants by MEM, air dried, mounted and arranged on adhesive tape subsequently placed onto conductive stubs. The samples were sputter-coated with gold for 50 seconds in a JEOL JFC-2300HR sputter coater (JEOL, Japan). The coated samples were scanned using a JEOL JSM-IT300 scanning electron microscope (JEOL, Japan) and imaged with a TRS Sharp:eye 2 × 2 k CCD camera (Troendle, Moorenwies, Germany).

The distribution map was drawn using Adobe Illustrator CC 2017 (Mac OS) based on spatial data exported from Google Earth Pro (2017).

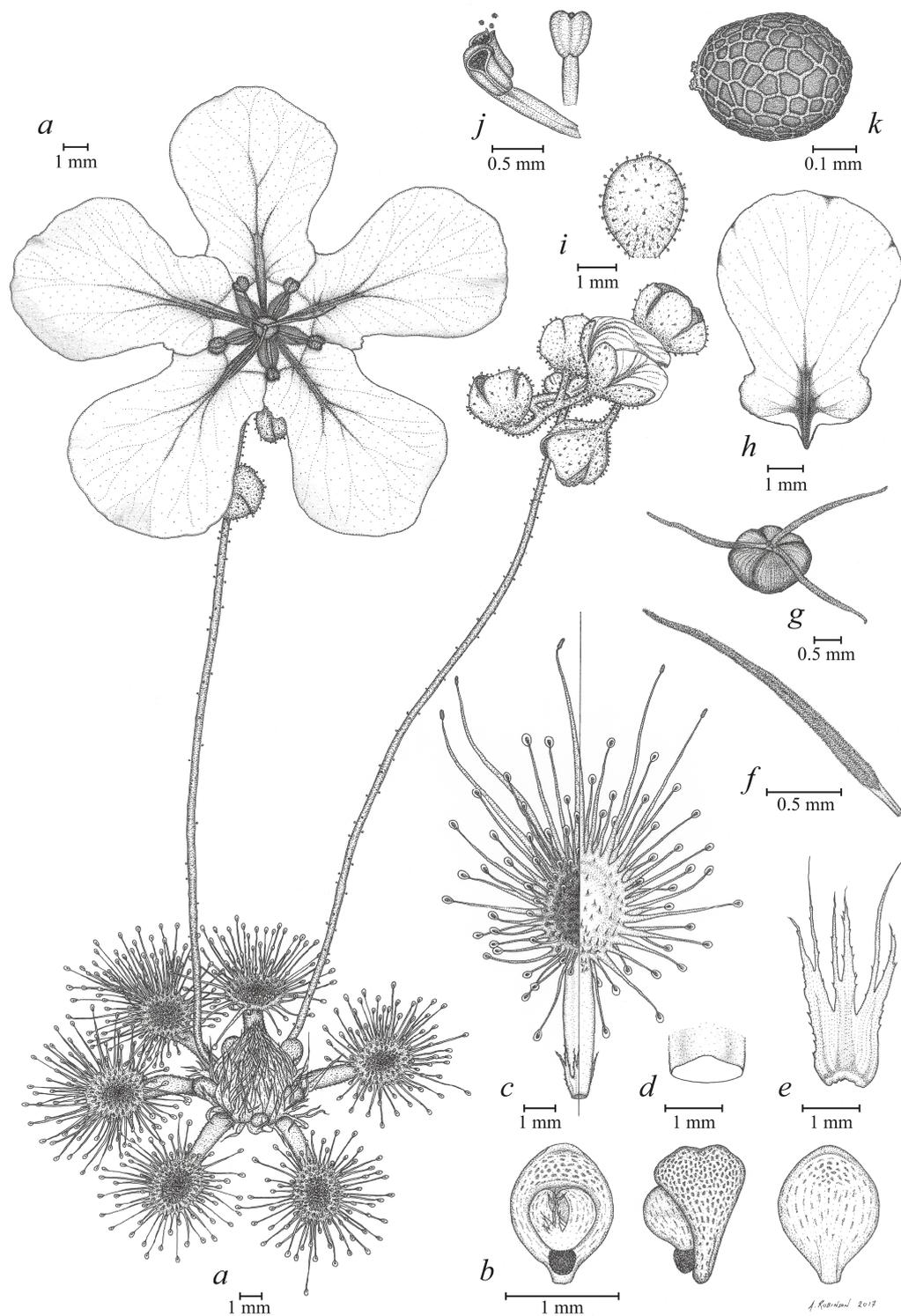
## Taxonomy

***Drosera albonotata*** A.S.Rob., A.T.Cross, Meisterl & A.Fleischm., *sp. nov.* (Figs. 1–2)

**Type:**—AUSTRALIA. Western Australia: Wandoo National Park, 320 m, generally in open areas on bare to gravelly, yellow to brown sandy clay loam with a moderate to dense shrub understorey in Wandoo (*Eucalyptus wandoo* and *E. accedens*) woodland, 01 October 2017, A.T. Cross & A.S. Robinson ACAR 001 (holotype PERTH-08935858!).

**Diagnosis:**—*Drosera albonotata* is similar to *D. miniata* from which it can be distinguished by (contrasting features in parentheses) 1) its petals, which are pandurate (broadly obtuse-ovate to obovate-subpandurate) and bear white, basal patches on either side of the midvein that are apparent both on the adaxial and abaxial petal surfaces (basal petal patches uniformly maroon-black), with more prominent venation including secondary and tertiary branching (less prominent, mostly limited to secondary branching), 2) its anther filaments, which are black at the base graduating to maroon-purple towards the thecae (filaments entirely white), 3) its sepals, which are apically more obtuse (more ovate) and inflorescences, both of which are distally more densely glandular than those of *D. miniata*, 4) by its more elliptic laminae (sub-orbicular) with an average of five Type II unifacial marginal glands (seven Type II unifacial marginal glands), the abaxial surface with a greater density of eglandular trichomes.

**Description:**—Perennial herb, roots fibrous, plants forming compact rosettes (0.8–)1.5(–2.2) cm in diameter, appressed to soil surface but old plants sometimes forming short stems to at least 4 mm tall, bearing withered remains of previous seasons' growth. Active leaves at anthesis (6–)8(–18); petiole 3–7 mm long, 0.4–0.7 mm wide near base, gradually dilating to 0.9–1.2 mm near lamina with slight constriction towards junction with lamina, in section somewhat narrowly elliptic, abaxially convex, adaxial surface slightly domed along midline and subconcave on either side, up to 0.5 mm thick, abaxial surface with scattered glands. Lamina sub-elliptic to sub-orbicular, 2.2–4.0 mm long, 2.0–2.5 mm wide, adaxial surface with insect-catching glands (tentacles), distal margin producing (3–)5(–7) Type II unifacial marginal glands *ca.* 4.2–6.8 mm long, retentive glands *ca.* 1.2–3.8 mm long, shorter stalked glands within, abaxial surface with scattered eglandular trichomes *ca.* 0.2–0.4 mm long. Stipular bud obovoid, distally tapered, basal half bristly, 3.7–5.5 mm long, 2.5–3.2 mm in diameter at base; stipules *ca.* 3.1–4.2 mm long, *ca.* 1.1–1.4 mm wide, up to 0.9 mm wide at base, 3-lobed; distal 1/2 to 1/4 of central lobe divided into 2 laciniae, each lacinia with slightly serrate margins; lateral lobes distinctly serrate or sometimes crenate on outer margin, inner margin entire, distal 1/2 to 2/3 lacinate into 2 segments, outer laciniae shorter than or equalling central lobe, innermost laciniae longer than central lobe. Gemmae ± broadly elliptic, tapered at the base, in profile asymmetrically pyriform, *ca.* 1.2 mm long, *ca.* 0.9 mm wide, *ca.* 0.9 mm thick. Inflorescences (1–)2(–3), each forming a (1–)5(–15)-flowered scorpioid cyme; scape (3.3–)4.9–7.2(–14.2) cm tall including peduncle, terete, 0.25–0.38 mm in diameter, basally arcuate, peduncle sparsely covered with very short, glandular trichomes, 0.049–0.15 mm long, longest and most dense towards apex of inflorescence; pedicels 1.8–4.5 mm long, pendulous in fruit, moderately glandular. Bracts if present narrowly lanceolate to subulate, 0.5–1.5 mm long, caducous (hence absent from most herbarium specimens). Flowers (16–)25(–28) mm in diameter. Sepals abaxially olive green, pink or maroon, the basal half fuscous, adaxially deep, blackish red throughout, ± ovate to suboblong, with an obtuse apex, 2.5–3.2 mm long, 1.8–2.7 mm wide, margins entire, abaxial surface bearing scattered glandular hairs *ca.* 0.18 mm long with translucent white stalk and red apical gland head, Petals 7–12 mm long, 4–8 mm wide at widest point, markedly pandurate, transition from proximal bout to centre bout of panduration often notched to form auriculae that often overlap with those of adjacent petals, adaxial surface orange with white basal patches either side of blackish-red midvein that are apparent in fresh specimens both adaxially and abaxially (fading in dried material), basal midvein very prominent, especially on abaxial surface, branching into 3 smaller veins that divide *ca.* 3 times before losing prominence, abaxial surface orange, slightly glaucous, margins and apex entire; petals imbricate



**FIGURE 1.** *Drosera albonotata* A.S.Rob., A.T.Cross, Meisterl & A.Fleischm. **a**—habit of a plant with two inflorescences at anthesis. **b**—gemma, *left* adaxial surface, *middle* lateral view, *right* abaxial surface. **c**—leaf with attached stipule as well as unifacial marginal glands, which can be relatively short-lived and not always apparent later in the season, *left* adaxial surface, *right* abaxial surface **d**—petiole cross-section. **e**—stipule, abaxial surface. **f**—style arm with stigma. **g**—gynoecium. **h**—petal, adaxial surface. **i**—sepal, abaxial surface. **j**—stamens, *right* sub-mature with intact anthers, *left* mature with extrorse longitudinal thecal dehiscence initiating at anther apex. **k**—seed. **a**, **c**, **h**, **j** from living type material prior to pressing, **b** from cultivated material, **d–g**, **i** from herbarium material, **k** from cultivated material visualised by SEM. Drawn by A. S. Robinson.



**FIGURE 2.** Living plants photographed *in situ*, showing *left* a flowering plant, and *right* a mature rosette. Photographs A.S. Robinson.

in bud. Stamens 5, 1.4–1.8 mm long; anther filaments blackish-red, sometimes apically maroon; thecae white; pollen yellow. Ovary black, broadly turbinate, apically depressed with 3 shallow grooves equidistant between styles running from apex to base, *ca.* 1.1–1.5 mm in diameter, to 0.7 mm high, surface microscopically verrucose. Styles 3, blackish-maroon, 2.2–4.1 mm long, flagelliform, held horizontally or curving upwards towards tips, *ca.* 0.12 mm in diameter at base tapering towards apex, stigmatic portion microscopically papillate. Seeds numerous, black, broadly ellipsoidal to almost hemispherical, 470–520  $\mu\text{m}$  long, 450–480  $\mu\text{m}$  in diameter, with a short funicular appendage on the terminal pole, testa isodiametrically reticulate, with anticlines thin and only shallowly raised, periclinal walls microscopically rugose.

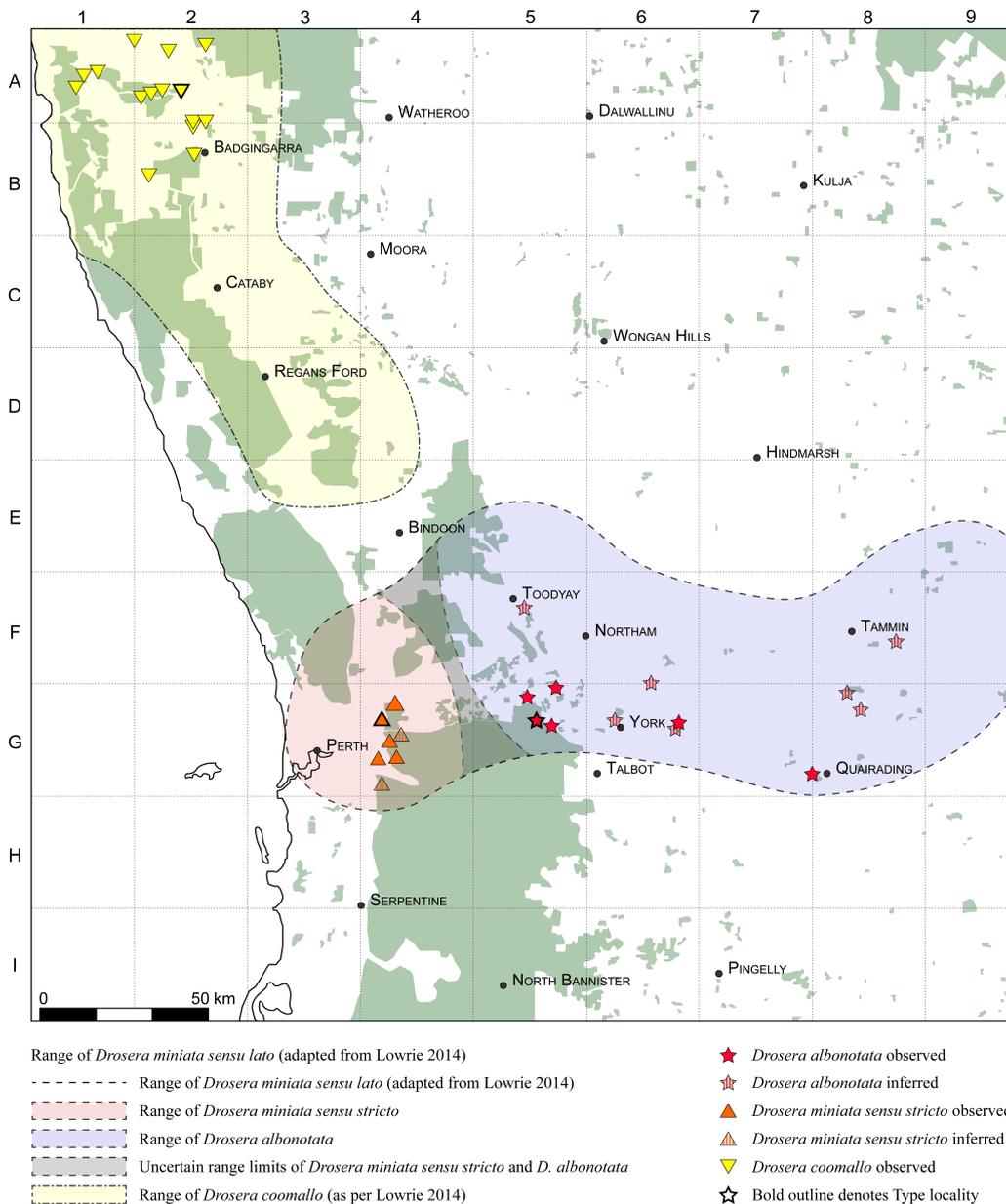
**Etymology:**—the specific epithet *albonotata* is derived from the Latin *albus* (white) and *notatus* (marked), a reference to the two basal marks of white on each petal, the overall effect of which is a collar of white around the floral centre. This feature is wholly absent from *Drosera miniata*.

**Phenology:**—Inflorescences emerge from early September and flowering generally occurs from mid- or late September to mid-October. Flowering is coincident with diminishing rainfall associated with the approach of summer, but at this stage in the season shallow excavations show that at least some subsurface moisture persists though the surface may appear dry in the absence of recent rains. The flowers are strongly helionastic and open only on sufficiently sunny days; since flowers continue to develop in overcast conditions, the arrival of sunny weather may precipitate mass flowering.

The largest plants and flowers observed during the study period were found in the two dampest sites, while flowers and rosettes were up to a third smaller in the driest site. Edaphic causes seem unlikely to account for this difference as a few larger plants and flowers were noted in the most sheltered, humid locations amongst the smaller plants and flowers typical of the driest site studied.

**Distribution and Ecology:**—*Drosera albonotata* is restricted to the western Wheatbelt region of Western Australia. Author confirmed populations exist within the Shires of Northam, York and Quairading. Additional unconfirmed records of the taxon exist from the shires of Cunderdin, Tammin and Kellerberrin, but it was not possible to verify

these owing to exceptionally dry conditions in the central Wheatbelt during the study period and the destruction of at least two sites for agricultural purposes. The records are tentatively supported by herbarium materials, which appear to consist of this taxon rather than *D. miniata*, though poorly pressed flowers or sterile material demand that observations of living material be made to establish certainty. A revised range of *D. miniata* (*s.str.*) is presented based on observational data and historic collections (Fig. 3), along with a proposed range for *D. albonotata* adapted from the range of *D. miniata* (*s.l.*) presented in Lowrie (2014).



**FIGURE 3.** A map of the central Western Wheatbelt with the ranges of *Drosera albonotata*, *D. coomallo* and *D. miniata* indicated. Observed locations are those visited by the authors or their colleagues where identity of the plants present was directly confirmed. Inferred locations are those where plants thought to be of the same taxon (indicated by herbarium collections or photographs taken by cooperative members of the public) may occur but which could not be confirmed by the authors, mainly as a result of aborted or extremely early flowering during the poor flowering season that coincided with the study period (drawing by A. S. Robinson).

*Drosera albonotata* occurs in Wandoo (*Eucalyptus wandoo* Blakely and *E. accedens* Fitzg. (Myrtaceae)) woodland on ridges and low rises, generally on gravelly slopes and pale yellow to brown sandy clay-loam soils with a moderate to dense shrub understorey including species such as *Leptospermum roei* Benth. (Myrtaceae), *Allocasuarina campestris* (Diels) L.A.S.Johnson, *A. humilis* (Otto & A.Deitr.) L.A.S.Johnson (Casuarinaceae), *Banksia armata* (R.Br.) A.R.Mast & K.R.Thiele, *B. sessilis* (Knight) A.R.Mast & K.R.Thiele (Proteaceae), *Gastrolobium parviflorum*

(Benth.) Crisp, *G. villosum* Benth. (Fabaceae), *Hakea lissocarpa* R.Br. (Proteaceae), *Hibbertia commutata* Steud., *H. hypericoides* (DC.) Benth., *H. vaginata* (Benth.) F.Muell. (Dilleniaceae), *Bossiaea eriocarpa* Benth. (Fabaceae), *Xanthorrhoea drummondii* Harv. (Asphodelaceae), *Trymalium ledifolium* Fenzl (Rhamnaceae), *Acacia pulchella* R.Br. (Fabaceae), *Hypocalymma angustifolium* (Endl.) Schauer (Myrtaceae), *Petrophile squamata* R.Br. (Proteaceae), *Anigozanthos humilis* Lindl. (Haemodoraceae), *Conostylis setigera* R.Br. (Haemodoraceae), *Dampiera lavandulacea* Lindl. (Goodeniaceae), *Melaleuca leptospermoides* Schauer (Myrtaceae), *Borya constricta* Churchill (Boryaceae), *Leschenaultia biloba* Lindl. (Goodeniaceae), *Pultenaea reticulata* (Sm.) Benth. (Fabaceae), *Daviesia decurrens* Meisn. (Fabaceae), *Mesomelaena tetragona* (R.Br.) Benth., *M. pseudostygia* K.L.Wilson (Cyperaceae), *Stylidium calcaratum* R.Br., *S. amoenum* R.Br., *S. ciliatum* Lindl. (Stylidiaceae) and *Drosera glanduligera* (Lehmann 1844: 37). In five of the six field sites studied, *Drosera albonotata* occurred in close proximity to *Gastrolobium villosum*; this species may be a reasonably reliable indicator of its localisation within a broader habitat area.

Investigated populations of *Drosera albonotata* ranged in size from tens of plants to the low hundreds. Plants grew singly or in sparsely scattered groups mainly in open areas free of leaf litter on bare clay or surface sand, sometimes partly buried, or amongst ironstone pea-gravel in full sun to slightly shaded sites beneath shrubs amongst trees. Average monthly temperatures during the September to October flowering period are 19–22.4 °C respectively (worldbank.org 2017, Mitchell *et al.* 2002). All *D. albonotata* sites lie within the 225–450 mm Western Australian Wheatbelt May–October Rainfall Zones despite a marked western trend in isohyet movement between the 1910–1999 and 2000–2011 data periods, contrasting with *D. miniata*, which is recorded from the wetter 450–700 mm and >700 mm zones (Western Australian Agriculture Authority, 2014: 10; Gibson *et al.* 2008: 201).

At two sites, beetle pollinators apparently of the same species were observed visiting flowers of *Drosera albonotata* (Fig. 4) and *Pultenaea reticulata*. At a Baker's Hill location, 5–6 individuals were seen to circulate amongst the ca. 25 flowers present in one population of plants occupying an area of 2 × 4 m. These beetles, which were visibly dusted with pollen, were recognised as members of the beetle subfamily Melolonthinae. A tentative genus identification of *Liparetrus* was subsequently offered by an expert entomologist (Nicholas Porch, pers. comms.). These beetle pollinators have also been observed to visit flowers of *D. glanduligera*, *D. hyperostigma* and *D. platystigma* (M. Meisterl, pers. observ.).

*Drosera miniata* appears to occur in areas experiencing higher average rainfall than *D. albonotata*, and favours lateritic shrublands with shallower soils amongst comparatively open, shorter stature vegetation with dominant plants including *Hakea trifurcata* (Sm.) R.Br., *H. undulata* R.Br., *Allocasuarina humilis*, *Beaufortia purpurea* Lindl. and an understorey of *Hibbertia hypericoides*, *Jacksonia condensata* Crisp & J.R.Wheeler, *Hypocalymma angustifolium* and *Melaleuca scabra* R.Br. The species is possibly more ruderal, favouring disturbed sites as well as the margins of paths (A. Cross and A. Robinson, pers. observ.; Keighery & Keighery 1993: 22). *Drosera miniata* is also documented from Mundy Regional Park (A. Cross pers. observ.) and Kalamunda National Park (A. Robinson, pers. observ.) in shallow sands and sand with clay respectively over granite in low open heathland, with accompanying species including *Acacia* Mill spp., *Verticordia* DC. spp., and *Calothamnus* Labill. spp., which are typical of granite scrub.

**Taxonomic notes:**—Morphological similarities (see also the key below) between *Drosera albonotata*, *D. miniata*, *D. coomallo* and *D. walyunga* indicate a close relationship between these species. This is confirmed by molecular phylogenetic data, which show the four in a statistically highly-supported clade of closely related sister taxa (A. Fleischmann, unpublished data). The chromosome number of *D. albonotata* was not counted as this value is not regarded as significant by the authors since karyotype seems to be of little value to infrageneric taxonomy in *D.* sect. *Bryastrum* and its sister section, *D.* section *Lasiocephala* Planchon (1848: 93). Members of these two lineages, which often present odd diploid chromosome numbers (Kondo & Lavarack 1984, Sheikh & Kondo 1995, Sidd James in Lowrie 2014), have holocentric chromosomes (Sheikh *et al.* 1995, Hoshi 2002) and thus often show intraspecific aneuploid series (see e.g., Hoshi 2002).

*Drosera albonotata* and *D. miniata* are morphologically similar enough that confident identification of sterile material may pose a challenge. However, this is typical of most pygmy *Drosera* species in the vegetative state (Lowrie 1989, 2014). While it is possible to distinguish between *D. albonotata* and *D. miniata* in the vegetative state with moderate confidence by counting the relatively short-lived Type II unifacial marginal glands if still intact (typically numbering 5 in *D. albonotata* and 7 in *D. miniata*), this characteristic is insufficient to exclude other pygmy *Drosera* species that may co-occur with them with certainty, though *D. callistos* and *D. hyperostigma* which occur in the western part of the *D. albonotata* range remain distinct, even when not in flower. Analysis of detached stipules and gemmae (if present) are required to increase confidence in the identification of sterile material. However, we recommend against the collection of pygmy *Drosera* in a non-flowering state as identification of dried sterile material is highly challenging at best.



**FIGURE 4.** A pollinator of *Drosera albonotata*, identified as a Melolonthid (Scarabaeidae) possibly in the genus *Liparetrus* (photograph by A.S. Robinson).



**FIGURE 5.** Comparison of the (*top*) adaxial and (*bottom*) abaxial surfaces of excised petals of *Drosera miniata* and *D. albonotata* collected at the respective type localities. Primary (1°), secondary (2°) and tertiary (3°) branching of the veins is indicated. Photographs and illustration A.S. Robinson.



**FIGURE 6.** Comparison of the flowers of (left) *Drosera albonotata* and (right) *D. miniata* from their respective type localities. Scale bar = 1 cm. Labels A, B and C indicate where comparative width measurements were made to test morphometric variation. The position of B was a fixed distance established in *D. albonotata* as the narrowest point of constriction of the centre bout (ii) of the pandurate shape, whilst A and C represent the widest points of the proximal (i) and distal (iii) bouts respectively (photographs and illustrations by A.S. Robinson).

Flowering plants of *Drosera albonotata* and *D. miniata* are clearly differentiated by the presence of distinctive white basal petal patches in *D. albonotata*, which give rise to the impression of a ring of white about the essential whorls. Differences in petal shape, venation and size between these species are also obvious (Fig. 5) and furthermore remain discernible in dried material. The degree of panduration in the petals of *D. albonotata* varies slightly between individuals, and in some cases includes notching that gives rise to basal auriculae that may overlap (Figs. 5–6). The flowers of *D. albonotata* (a maximum of 2.8 cm in diameter) are the second largest recorded for pygmy *Drosera* species, after those of *D. leucoblata* from the Cranbrook region (to 3.5 cm in diameter; Lowrie 2014; MEM & AF pers. observ.). Although *D. sewelliae* is occasionally regarded as the largest-flowered pygmy *Drosera* species (Lowrie 1989: 166, Lowrie 2014: 816) given its broader, more substantial petals and its large rosette to flower size ratio, the same source coincidentally ascribes the largest flower diameter to *D. leucoblata* (Lowrie 2014: 556).

The differences in venation, colouration and shape between the petals of *Drosera albonotata* and *D. miniata* are consistent. However, their petals dry to similar colours, while the characteristic white petal marks of *D. albonotata* fade somewhat in herborised material. Since subpandurate forms of *D. miniata* are also known, this has the potential to confound herbarium analyses. As a result, the value of morphometric data in determining identity was investigated using ratios (see Materials and Methods). The measurement points used are indicated in Fig. 6, with samples made from 22 randomly selected individuals of each species across each of the different localities studied. The A/C ratio in petals of *D. miniata* was slightly higher (0.70) than in *D. albonotata* (0.65), which is to be expected given the shape of its petals, which tend to be slightly wider towards the apex than the base. However, a pronounced difference was observed for the A/B ratio, which more specifically measures the degree of panduration, with A/B far higher for *D. albonotata* (1.14) than *D. miniata* (0.85). Generation of normal Q-Q plots showed that both data sets exhibited normality of distribution, with all data points lying well within the 95% confidence intervals (CI) for the normal quantiles. Application of the Levene's test of homogeneity of variance (Leven 1960) indicated that equal variance could be assumed for set A/C ( $p > 0.05$  at 0.9867) but not A/B ( $p < 0.05$  at 0.002845), therefore a Welch Two-sample  $t$ -test (Welch 1938) was used to repeat analysis of set A/B; this gave rise to the same outcome as an analysis assuming equal variance. The results of the Two-sample (A/C) and Welch Two-sample (A/B)  $t$ -tests found that:

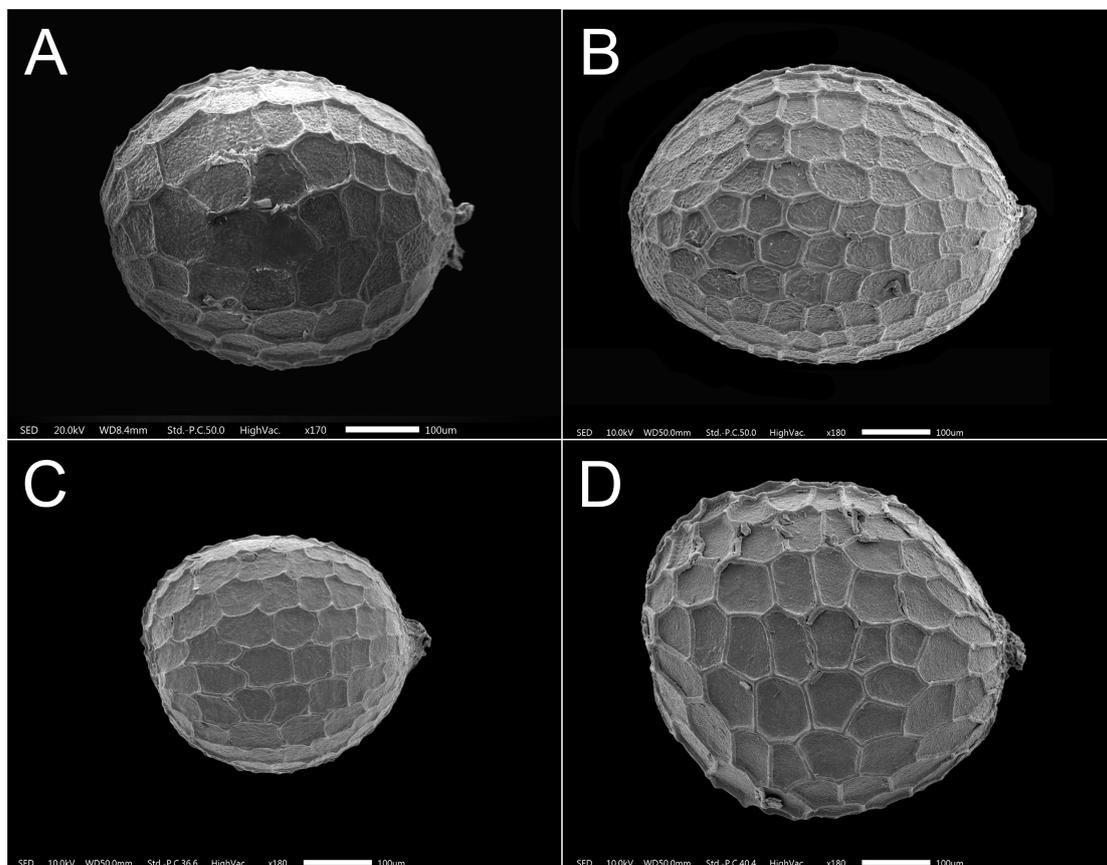
- A/C:  $t(df = 42) = -1.8531$ ,  $p = 0.0701$ , 95% CI for the difference in mean ratio [*D. albonotata* 0.65, *D. miniata* 0.70], indicating no statistical significance.
- A/B:  $t(df = 30.44) = 17.406$ ,  $p = <0.001$ , 95% CI for the difference in mean ratio [*D. albonotata* 1.14, *D. miniata* 0.85], indicating statistical significance to the highest possible degree of certainty.

These results suggest that calculation of the ratio between points A and B may be reliable indicators of species identity, with *Drosera albonotata* in the (1.01–)1.14(–1.24) range and *D. miniata* in the (0.79–)0.85(–0.90) range.

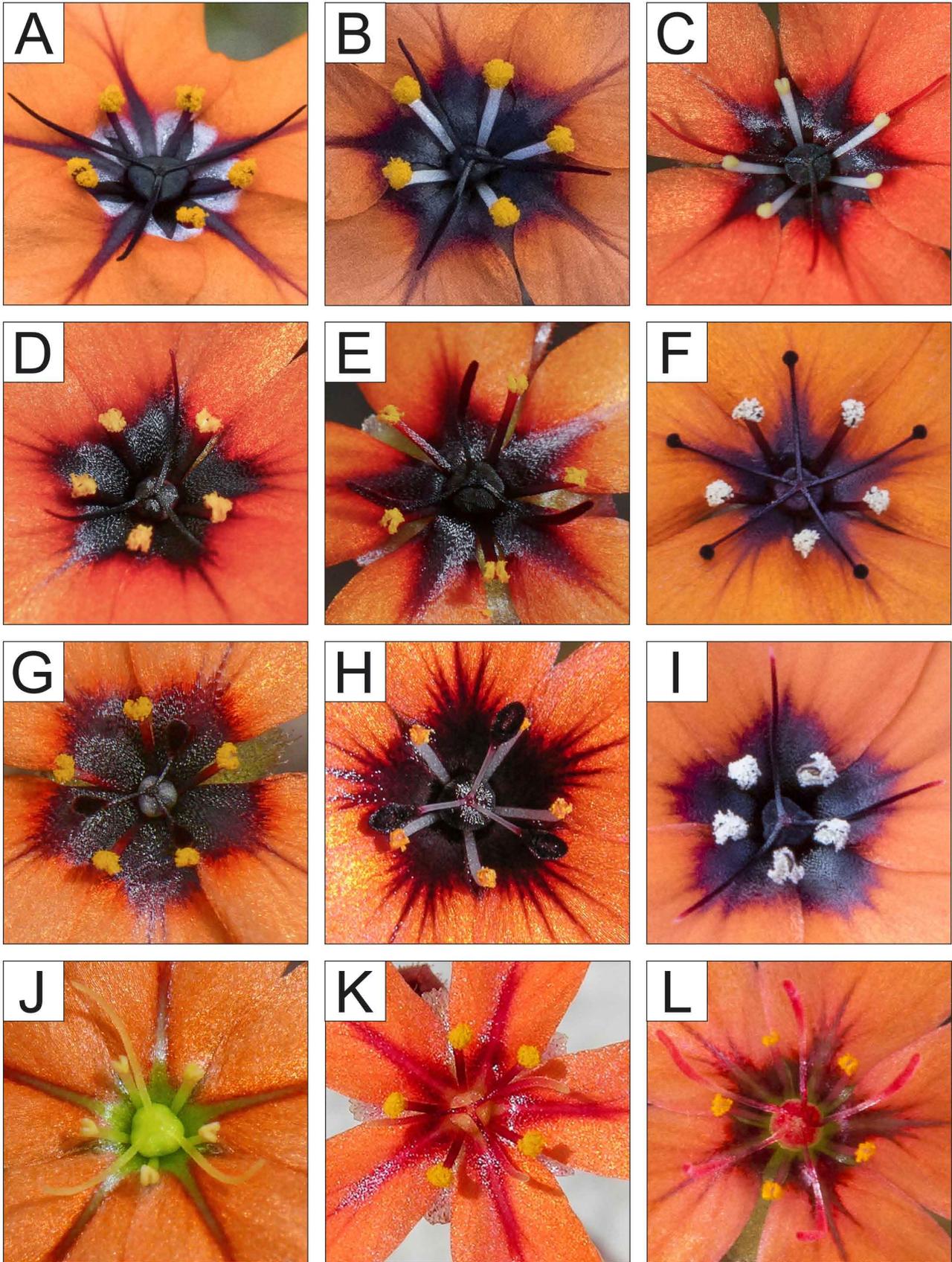
Whilst essentially irrelevant in the living state given the obvious differences in floral colour pattern, this method of analysis is valuable when analysing herbarium specimens in which the most obvious diagnostic colour characteristics of living material have faded, the white patches of *Drosera albonotata* being challenging to discern, though still present. *Drosera walyunga* (untested) may exhibit similar ratios to *D. albonotata* on account of its pandurate petals, however *D. walyunga* can be distinguished in dried material by its sepals, which are basally more densely glandular, and its narrower petals. In live material, it is additionally distinguished by its metallic white or pale pink petal colour, petals with less pronounced venation and a less pronounced or absent hip in the centre bout, and most notably by its narrower, white anther filaments, pale green ovary and white styles (filaments, ovary and styles black or rarely deep reddish-purple in *D. albonotata*).

The separation of *Drosera albonotata* from *D. miniata* does not require a recircumscription of the latter species; the type of *D. miniata* (Diels 4538, B!) has white anther filaments and dark styles, while the petals have no white basal markings. Diels (1904, 1906) noted that *D. miniata* almost always produces 1 solitary inflorescence and while this is true for the greater part of specimens examined, the authors noted a minority of otherwise typical *D. miniata* plants with 2, 3, 4 and, in one case, 5 inflorescences per plant (even on Diels' type). In contrast, *D. albonotata* often produces 2 scapes. Since recent treatments of *D. miniata* have conflated these two taxa (e.g. Lowrie 1989, 2014; Lowrie *et al.* 2017) care must be taken to discount characteristics previously attributed to *D. miniata* that are clearly derived from material representing *D. albonotata*. The main differences are those stated in the differential diagnosis and further reflected in the diagnostic key.

SEM was used to compare the seeds of the natural group comprised of *Drosera albonotata*, *D. coomallo*, *D. miniata* and *D. walyunga* (Fig. 7). The testa ornamentations of *D. albonotata*, *D. miniata* and *D. walyunga* are very similar. While the reticulation in *D. albonotata* and *D. walyunga* appears coarser (wells delimited by anticlines *ca.* 60–70  $\mu\text{m}$  diam.) and less oblong than that of *D. miniata* (wells *ca.* 40–60  $\mu\text{m}$  long  $\times$  35–45  $\mu\text{m}$  wide), the differences may not be significant between all populations. However, the slightly smaller and more rounded seeds of *D. coomallo* can apparently be told apart based on size and testa ornamentation, with the anticlines lightly raised at each junction. This may further support the separation of this species from *D. miniata*, as evidenced by Lowrie (2014).



**FIGURE 7.** Seeds of **A** *Drosera albonotata*, **B** *D. miniata*, **C** *D. coomallo* and **D** *D. walyunga* visualised by SEM (image A by M.E. Meisterl; B, C, D by H. Halbritter).



**FIGURE 8.** Comparison of the flowers of all twelve orange-flowered *Drosera* species in *D.* section *Bryastrum*. **A** *Drosera albonotata*, **B** *D. miniata*, **C** *D. coomallo*, **D** *D. bindoon*, **E** *D. callistos*, **F** *D. sewelliae*, **G** *D. hyperostigma*, **H** *D. platystigma*, **I** *D. barbiger*, **J** *D. echinoblastus*, **K** *D. leucoblasta*, **L** *D. pulchella* (orange flowered variant). Flowers not all shown at same scale (photographs C, D, E, G, H, J, K by A. Fleischmann; A, B, F, I, L by A.S. Robinson).

**Conservation status:**—Direct observations of *Drosera albonotata* *in situ* satisfy the IUCN Red List Criteria of VU B2ac(iv);D2 (IUCN, 2012), i.e. the species has an AOO < 2000 km<sup>2</sup> (known sites estimated at 2.28 km<sup>2</sup> in total), is known from fewer than ten locations (only recorded from six relatively small populations, comprising *ca.* 25–150 individuals each), and pronounced fluctuations have been observed in the number of mature individuals at each location between seasons (A. Robinson, pers. observ.). These occur in fragmented areas that include unprotected remnant habitat spread over 87 km east to west (Fig. 3), surrounded by a matrix of cleared agricultural land. Thus, although additional potential habitat for this species exists in patches of remnant and secondary woodland in the region, little of this habitat is protected and populations are likely to be highly fragmented. Marked patterns of diminishing rainfall recorded for the eastern extent of the Wheatbelt (e.g. Gibson *et al.* 2008) may represent a long-term threat to the easternmost localities of this species. Furthermore, trends of clearing in the Avon wheatbelt region (currently at around 97% of all vegetation) have made this one of the most cleared regions in the southwest (Bradshaw 2012, Saunders 1989). This clearing has yet to cease, and ongoing habitat loss and degradation are real threats to this species, as evidenced by the conversion of at least two previous collection sites of *D. albonotata* to farm and residential land.

**Diagnostic key to the orange-flowered species of *Drosera* sect. *Bryastrum*:**—Taking into account the observations made during this study, a revised diagnostic key to the orange-flowered species of *Drosera* section *Bryastrum* has been devised as follows (a comparison of the flowers of all twelve species is provided in Fig. 8).

1. Upright stem-forming habit, leaves semi-erect; lamina elliptical to narrowly obovate (tentacle-bearing part of the leaf clearly longer than wide, not including tentacle length); scape with arcuate base; sepals densely covered with red glandular hairs (appearing reddish-villose); styles 3–4(–5); pollen white [the only other species with (4–)5 styles in combination with densely villose-glandular sepals and white pollen is the flat-rosetted *D. sewelliae*].....*D. barbiger*
- Flat-rosetted habit (aged specimens sometimes forming columns), leaves rosulate; lamina broadly elliptical, broadly obovate, circular, or broadly transversely elliptical (tentacle-bearing part of the leaf about as long as wide, not including tentacle length); scape with erect base; sepals glandular to subglabrous; styles 3–5; pollen yellow, bright orange, or white .....2
2. Petiole lanceolate, broadest towards the middle, up to 2 mm wide at greatest width; petals ≤ 6 mm long; styles 5, white; anther filaments white or with white base graduating pink; plants of usually perennially wet habitats .....*D. pulchella*
- Petiole very narrowly triangular (sometimes appearing almost linear), broadest width at the base, up to 1 mm wide; petals 7–10 mm long; styles 3–5, dark, reddish or yellowish-green; anther filaments dark or white; plants of generally seasonally drier habitats...3
3. Stigmas widened (obovoid, clavate, globose or peltate), clearly distinct from the terete styles; styles 3–5.....4
- Stigmas filiform or subulate, not distinct from the styles; styles 3 (rarely 4 in exceptional, aberrant flowers).....6
4. Stigmas peltate; style-arms white (rarely pink tinged), contrasting with the dark stigmas; anthers with white filaments; petal base dark-reddish (rarely pale red) with reddish streaks protruding into the orange part of the petals .....*D. platystigma*
- Stigmas obovoid-clavate or globose; styles and stigmas uniformly dark; anthers with dark filaments; petal base very dark reddish-black, surrounded by a diffuse reddish area which is clearly discernible from the orange petal colour .....5
5. Styles 3; pollen yellow; stigmas obovoid-clavate; styles (including stigmas) 1.0–1.5 mm long, shorter than the anthers or equalling them in length; styles not exceeding the dark central eyespot of the flower; ovary grey; petals 6–7 mm long; sepals sparsely covered with short-stalked glands (appearing subglabrous to the naked eye in dried specimens); stipules 3-lobate, the central lobe divided into 3 lacinate segments .....*D. hyperostigma*
- Styles (4–)5; pollen white (rarely yellow); stigmas globose; styles (including stigmas) 3–4 mm long, much longer than the anthers; styles clearly exceeding the dark central eyespot of the flower; ovary dark-reddish to black; petals 8–10 mm long; sepals densely covered with long-stalked glands (appearing hairy to the naked eye in dried specimens); stipules 3-lobate, the central lobe divided into 3 entire segments.....*D. sewelliae*
6. Petals uniformly orange (at most with reddish-maroon midvein, but never with all-encompassing blackish guide mark or white taint at the base); ovary yellowish-green, sometimes tinged dark-orange-red, rarely entirely dark (as in some cases for *D. leucoblasta* from the Esperance and Cranbrook regions); stigmas (i.e. the apex of each of the styles) yellowish-green, yellow or orange (even if styles dark-reddish, then stigmatic tip contrasting in colour, being much paler).....7
- Petals bicoloured, orange with dark reddish-black guide mark or white taint at the base; ovary dark-reddish-brown to black; stigmas and styles uniformly dark-reddish-brown to black .....8
7. Petals narrowly obovate to elliptical, not overlapping and barely touching at their bases (subjacent sepals, at least their tips, usually visible from above); stigmas subulate, with obtuse apex; anther filaments reddish to dark-red, at least in their upper part; ovary yellowish-green, but often reddish tinged, rarely entirely dark; stipule 3-lobate, lateral lobes apically 2–3-lacinate, all fringes subequal in length; all stipule fringes concavely in one plane (therefore dormant stipule bud appearing smooth in side view); pedicels erect in fruit; plants occurring south-east of Perth .....*D. leucoblasta*
- Petals obovate, overlapping at their bases (subjacent sepals not visible from above); stigmas filiform, tapering to pointed apex; anther filaments uniformly yellowish-white; ovary yellowish-green; stipule 3-lobate, lateral lobes apically 4–5-lacinate, the lowermost lacinia longest, exceeding all other fringes; stipule fringes of lateral lobes pointing outwards (therefore dormant stipule bud appearing bristly); pedicels patent (semi-erect, held horizontal) in fruit; plants occurring north of Perth .....*D. echinoblastus*
8. Fruiting pedicels erect; lamina elliptical to broadly elliptical (slightly longer than wide, not including tentacle length); stipules with entire outer margins; petals broadly obovate to narrowly obovate .....9
- Fruiting pedicels reflexed; lamina usually suborbicular to orbicular (about as long as wide, not including tentacles' length); stipules with serrate outer margins; petals obovate, elliptical or pandurate .....10

9. Styles (including stigmas) 1.0–1.2 mm long, subequal to the anthers in length; stigmas subulate (and usually curved upwardly in living specimens), with obtuse apex; petals obovate, elliptical or narrowly obovate; peduncle > 5 cm tall ..... *D. callistos*  
 - Styles (including stigmas) 3.0–3.5 mm long, much exceeding the anthers in length (about twice as long); stigmas filiform, tapering to acute apex; petals broadly obovate; peduncle ≤ 5 cm tall ..... *D. bindoon*
10. Anther filaments white (also recognizable in dried specimens); petals obovate to slightly pandurate ..... 11  
 - Anther filaments dull (dark maroon red to brownish-black; colour identical to that of the styles and also maintained in dried specimens); petals notably pandurate in outline (the white petal mark between dark base and orange part is clearly evident in fresh specimens and a suitable taxonomic character to distinguish it from all other orange-flowered species with a dark centre, but it is not always clearly discernible in dried materials) ..... *D. albonotata*
11. Peduncle and sepals densely microscopically glandular; petals obovate (length:width ratio = ca. 3:2) to elliptical ..... *D. coomallo*  
 - Peduncle and sepals subglabrous, sparsely glandular; petals narrowly obovate (length:width ratio = ca. 2:1) to subpandurate .....  
 ..... *D. miniata*

Finally, gemma shape is a further suitable taxonomic character by which the four species-groups of orange-flowered species of *Drosera* section *Bryastrum* can be distinguished (Lowrie 1989, 1998, 2014). However, these characters are omitted from the key as gemmae are generally not present on flowering specimens (the most frequent condition by which orange-flowered pygmy *Drosera* are identified as such in the field and in the herbarium; sterile specimens of most pygmy *Drosera* cannot be identified to species-level with certainty without at least knowledge of the exact collection locality). Gemmae-bearing individuals of the species treated here can be assigned to the following four species-groups:

- a) Gemmae flat (dorsiventrally flattened), scale like, ovate to elliptical in outline; largest width below the middle; gemmae apex pointed, the very tip obtuse; growth point small, barely discernible with the naked eye [*D. pulchella*];  
 b) Gemmae flat (laterally compressed), asymmetrically ellipsoid; largest depth near the apex; gemmae apex obtuse; growth point small, barely discernible with the naked eye [*D. platystigma*];  
 c) Gemmae asymmetrically obovoid to turbinate, with the largest width below the middle, the largest depth near the apex; two thick lateral wings or dilatations; gemmae apex often with small apical depression and microscopically verrucose; growth point large, occupying at least 1/3 of the ventral length [*D. barbiger*, *D. bindoon*, *D. callistos*, *D. echinoblastus*, *D. hyperostigma*, *D. leucoblasta*, *D. sewelliae*];  
 d) Gemmae laterally compressed, asymmetrically pear-shaped to ellipsoid, with largest diameter (depth) at a bulge on the upper dorsal part; without any lateral wings or dilatations; gemmae apex obtuse; growth point large, occupying at least 1/3 of the ventral length [*D. coomallo*, *D. miniata*, *D. albonotata* (as well as *D. walyunga*, which is not orange-flowered)].

**Additional specimens examined:**—*Drosera albonotata* (Paratypes):—AUSTRALIA. Western Australia: Wandoo National Park, Mt. Observation Rd, 01 October 2017, *A.T. Cross & A.S. Robinson ACAR 002*, (PERTH!); Northam, Baker’s Hill, 02 October 2017, *A.T. Cross & A.S. Robinson ACAR 003* (PERTH!); Northam, Clackline, 02 October 2017, *A.T. Cross & A.S. Robinson ACAR 004* (PERTH!); Northam, Clackline, 07 October 2008, *F. Hort & J. Hort 3319* as *D. miniata* (PERTH!); York, Quairading Rd, 12 October 1977, *N.G. Marchant 77/162* as *D. miniata* (PERTH!) [locality now turned into a wheat field; ASR pers. observ. 2017]; Quairading, Tammin National Park, 02 August 1968, *R.D. Royce 8439* as *D. miniata* (PERTH!); York, Quellington, 28 September 1901, *C. Andrews s.n.* as *D. miniata* (PERTH!); Toodyay, Darling Range, 22 October 1983, *A. Lowrie 12* as *D. miniata* (PERTH!); York, near Mokine Rd, 07 October 1933, *W.E. Blackall 3294* as *D. miniata* (PERTH!) [locality now developed for residential purposes, ASR pers. observ. 2017]; Tammin, Gardner Flora Reserve, 27 Sep 1974, *L. Debuhr 3816* as *D. miniata* (PERTH!).

*Drosera coomallo*:—AUSTRALIA. Western Australia: Coomallo telephone exchange, Marchagee Track, 27 September 2000, *Allen Lowrie 2478* (PERTH!, holotype); Dandaragan, Hakea Reserve, 27 October 2002, *F. Hort & J. Hort 1875* as *D. miniata* (PERTH!); Dandaragan, S. Jurien Road East, 09 September 1999, *J.W. Horn 2317* as *D. miniata* (PERTH!).

*Drosera miniata*:—AUSTRALIA. Western Australia: Swan, Swanview, in steinig kiesigem Boden in sonnigen Lagen [in stony-gravelly soil at sunny sites], 120 m, 30 September 1901, *L. Diels 4538* (B!, type); Swan, Talbot Rd Res., 10 October 2009, *K.R. Thiele 3867* (PERTH!); Swan, Red Hill, 10 November 1991, *A. Lowrie 511* (PERTH!); Mundaring, Helena Valley, October 1992, *S. James 92.10/1* (PERTH!); Mundaring, Helena Valley, 16 October 1977, *J. Seabrook 365* (PERTH!); Gosnells, Ellis Brook Valley Reserve, 25 September 1999, *H. Bowler 151* (PERTH!).

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