


A new species of critically endangered edible yam endemic to northern Madagascar, *Dioscorea irodensis* (Dioscoreaceae) and its conservation

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Summary. Morphological character data are used to show that a distinct morphotype of *Dioscorea* L. from the Irodo valley (East of Sadjoavato) in Antsiranana Province of Madagascar is an undescribed species, differing in its leaf arrangement, pubescence form and male inflorescence structure from all other taxa. It is described as *Dioscorea irodensis* Wilkin, Rajaonah & Randriamb., illustrated and a distribution map and ecological information provided. It is known from three sites, but is likely to have been eradicated from one of them. The population that has been studied in the field contains a very low number of adult plants. Tubers have been extracted for use as food at a level that appears to be unsustainable. Thus its provisional IUCN conservation status assessment is that it is critically endangered (CR). Its vernacular name in Irodo is *Bemandry*.

Famintinana. Ny toetra sy ny bikan'ny oviala dia azo ampiasaina hanehoana fa miavaka ny oviala iray, izay hita tao anatin'ny lohasahan'Irodo (Atsinanan'i Sadjoavato, faritanin'Antsiranana) ao Avaratr'i Madagasikara, ary tsy mbola voasoritra ny mombamomba azy. Mampihavaka azy amin'ny hafa ireto toetra manaraka ireto: ny fipetraky ny ravina, ny fisian'ny volo, sy ny firafitry ny tahom-bony lahy eo aminy. Nosoritana ho *Dioscorea irodensis* Wilkin, Rajaonah & Randriamb. izy ity, nampiratiana an-tsary ny momba azy, namoahana saritany ny toerana misy azy, ary nomena ireo vaovao ara-ekolojika mikasika azy. Vondrona oviala miisa telo fara-faha-betsany no fantatra fa misy azy, ary efa ho fongana ny iray amin'ireo. Ny vokatry ny fanadihadiana izay natao tamin'ny vondrona oviala misy no nahitana fa vitsy ny fototra oviala lehibe afaka mamoa, ary maro ireo nohadiana ho sakafo, izay mamaritra sahadry fa tsy hateza io karazana io. Noho izany, ny sata fiarovana vonjimaika IUCN dia manombana fa zavamaniry tena tandindomin-doza (CR) io karazana oviala io. *Bemandry* no fiantso io karazana oviala io any Irodo.

Key Words. conservation, critically endangered, distribution, edible, *ex situ*, *in situ*, Madagascar, morphology, new species, yam.

Introduction

The taxonomic and nomenclatural history of *Dioscorea* in Madagascar was summarised in Wilkin & Randriamboavonjy (2012). Since the publication of that paper, field research in the North of the country has been undertaken by the authors of this paper under the project "Conserving Madagascar's yams through cultivation for livelihoods and food security", funded by the UK Darwin Initiative. This led to the discovery of a morphotype collected from three sites east of the RN6 near Sadjoavato in Antsiranana Province that potentially represented a new taxon. The morphotype has extensive and sometimes

dense pubescence and vegetative stem leaves in clusters on short shoots, traits it shares with *D. ovinata* Baker. Two taxa of the *D. sambiranensis* R. Knuth complex (Wilkin *et al.* 2009) are also pubescent (*D. sambiranensis* and *D. namorokensis* Wilkin) but their leaves are always borne singly in an alternate arrangement. The first specimen collected of the morphotype was misidentified as *D. sambiranensis*, which has similar indumentum but in addition to the leaf arrangement, differs in having a long-pedicellate male flower (Wilkin *et al.* 2009), flat discoid floral torus and thicker leaf blades. Elements of the *D. soso* Jum. & H. Perrier complex, found further south, also have

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similar indumentum, however these taxa also have solitary, alternate leaves and short petioles in relation to blade length, by which they differ from *D. ovinata* and the plants from East of Sadjoavato. Thus this entity was compared with *D. ovinata* to assess its taxonomic status.

Materials & Methods

The hypothesis that the morphotype from East of Sadjoavato represents a distinct taxon was tested by morphological comparison with existing species of *Dioscorea* from Madagascar as defined in the introduction. The most detailed comparison was made with *D. ovinata*. Knowledge of the systematics of the yams of Madagascar is based on comparative morphological study and a database of 1346 specimens from the following herbaria: B, BM, G, K, MO, P, TAN, TCD, TEF, UPS and WAG (herbarium acronyms follow Thiers (2012)) and in the field. The specimens examined in the study of the new species are cited below. Floral dissections were carried out and measurements made using a Leica MZ95 with a measuring eyepiece. Vegetative and inflorescence characters were measured with a dial caliper.

Digital latitude and longitude of the four specimens of the morphotype were used to generate Map 1, which was created with SimpleMappr (Shorthouse 2010; <http://www.simplemappr.net>). These data were also imported into GeoCAT (Bachman *et al.* 2011; <http://geocat.kew.org/>) in order to calculate extent of occurrence (EOO) and area of occupancy (AOO).

Results and Discussion

The fruit, seed and tuber morphology of the specimens examined unequivocally place the morphotype from East of Sadjoavato within the Malagasy clade of *Dioscorea* (Wilkin *et al.* 2005; Viruel *et al.* 2016). This result is further corroborated by unpublished phylogenetic analyses of multiple plastid markers. There are clear vegetative and reproductive morphological differences between the new entity and all other known species (see Introduction and Table 1). Thus it is described as a new species, *D. irodensis* Wilkin, Rajaonah & Randriamb. below.

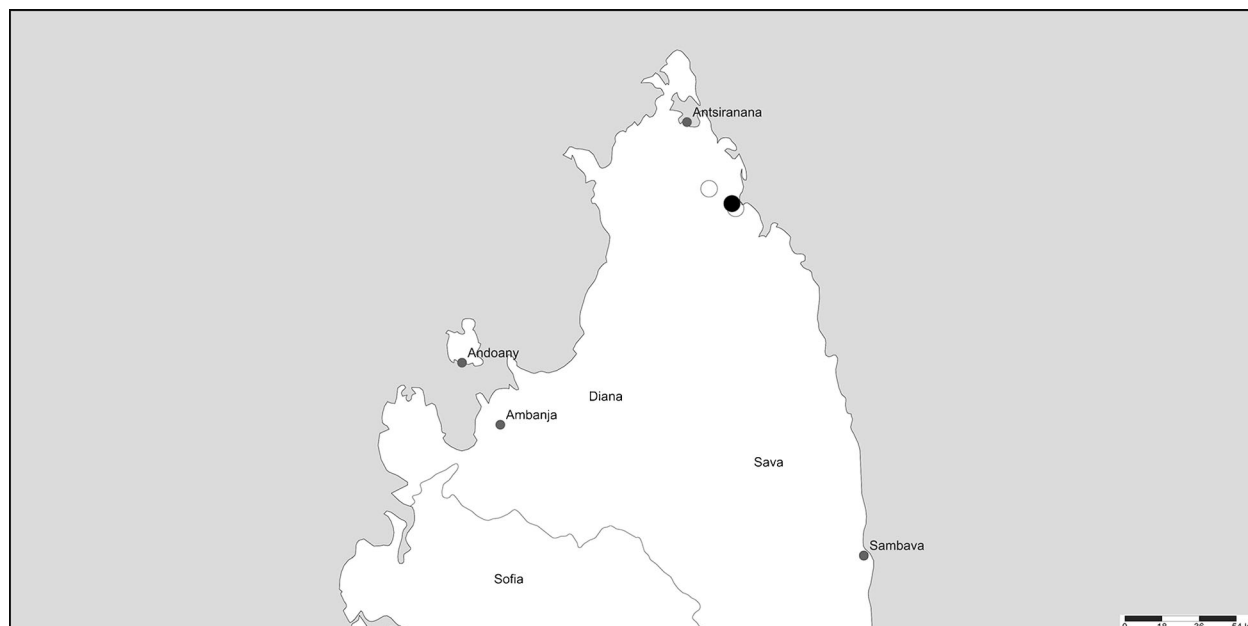
GeoCAT yielded figures of 7.3 km² for EOO CR and 12 km² for AOO based on a user defined cell width of 2 km, as recommended by IUCN Standard and Petitions Subcommittee (2014). Both the EOO and AOO are below the thresholds for categorisation as EN; the EOO is also below the threshold for categorisation as CR (IUCN 2001).

Taxonomic Description

***Dioscorea irodensis* Wilkin, Rajaonah & Randriamb., sp. nov.** Type: Madagascar, Antsiranana: Diana, Antsiranana II, Anivorano, Irodo, *ala fady* S of village towards Irodo river estuary, 12°39'6.3"S 49°31'38.2"E, ♀ fr. 8 Feb. 2015, P. Wilkin, J. A. Kennerley, F. Rakotomasolo, M. Hamido & M. Tsaratiana 1675 (holotype TAN!; isotype K!).

<http://www.ipni.org/urn:lsid:ipni.org:names:77159808-1>

A twining *vine* to c. 6 m in height. Current season's *tuber* (Fig. 2C) (previous seasons' also present) to c. 80



Map 1. Map showing the distribution of *Dioscorea irodensis* specimens in northern Madagascar. The known population is indicated by solid black circles (two overlapping points). Populations of unknown status or potentially eradicated are indicated by open circles (one point partially overlapping solid black points; see also Conservation Status section). Major population centres (grey circles) and subprovinces are indicated.

Table 1. A comparison of the principal characters differentiating *Dioscorea irodensis* from *D. ovinala*.

Character	<i>D. ovinala</i>	<i>D. irodensis</i>
Tuber habit and size	Vertical in substrate, 50 – 100 × 10 – 15 cm, fusiform	Horizontal in substrate, to c. 80 × 15 cm, cylindrical
Indumentum	Often dense, velutinous and soft to touch, especially on leaf lower surface and inflorescences	Sometimes dense but coarse rather than soft and velutinous
Leaf arrangement	Solitary to in clusters of up to 4 on short herbaceous branches	Usually in clusters of up to 7 on short herbaceous branches, especially on primary vegetative shoots, sometimes solitary towards shoot apices
Leaf texture	Chartaceous to thickly so, not translucent even when dry	Thinly chartaceous to membranous, sometimes translucent when dry
Male inflorescence	1 – 4 flowers per node, dense, sessile or rarely with a pedicel to 0.5 mm long	Dense cymular clusters of (1 –) 2 – 8 flowers on 0.2 – 1.1 mm long pedicels
Male flower habit and tepal shape	Tepals spreading, making flower rotate, tepals ovate with obtuse apices	Tepals ascending with recurving apices, making flower shallowly bowl-shaped, ovate to elliptic or broadly so with rounded to acute apices
Fruit dimensions and outline shape	26 – 40 × 17 – 30 mm, obovate to suborbicular	23 – 28 × 15 – 19 mm, obovate to oblong-obovate
Fruit wing form during development	Each wing c. 4 – 5 mm thick and fleshy when immature, when dry with clearly differentiated exocarp	Immature wing thickness not exceeding 1 mm, not fleshy, when dry wing single-layered.

× 15 cm, cylindrical, tapering towards base and apex, horizontal in substrate, c. 20 – 50 cm deep, epidermis pale cream, parenchyma pure white, watery, not mucilaginous, apex curved 90° and narrowing to c. 3 mm, subtended by a c. 8 mm diam., thickened crown; stem above crown erect, annual, below ground white, above ground to 3 mm in diam., terete, unarmed, tough and wiry, dark purple with green flecks to brown and mottled paler, drying dark brown on principal stems, paler on branches, possessing cataphylls towards stem base to c. 4 × 3 mm, very broadly ovate, apex acute to short-acuminate, amplexicaul, thick and leathery; axillary bulbils not present; nodes on main stems and towards base especially swollen to c. 6 mm, often with a pair of rigid, acuminate lateral projections, occasionally more projections present. *Indumentum* coarse, of colourless multicellular hairs with small inflated bases, to 1.5 mm long, erect to spreading and straight to curved, basal stems subglabrous, pubescence more extensive at nodes and on younger (narrower and angled) stems, dense on petioles and leaf blade, (lower surface less so with age), densest on buds and leaves in early stages of expansion (during male anthesis), inflorescences pubescent, most densely so on cymule bracts and tepal dorsal surfaces, especially outer whorl, capsules glabrescent but less so along axis and around style base. *Leaves* borne in clusters of up to 7 on short herbaceous branches, especially on principal stems, sometimes solitary, especially on narrower stem branches and towards apices, alternate, blade (20 –) 29 – 71 × (14 –) 22 – 75 mm, ovate to very broadly so or ovate-orbicular, entire, thinly herbaceous when fresh, thin and sometimes papery when dry, some-

times translucent, drying grey to pale olive-green, paler below, paler narrowly oblong micro-organs visible at high magnification, definition and density variable, when fresh blade dark green above, paler below, veins 5 – 7, 3 reaching apex, base cordate to subtruncate, sinus depth to 8 mm, apex rounded or obtuse to acute or short-acuminate, with a forerunner tip to c. 2.5 × 1.2 mm, deltoid, green to weakly brown-pigmented when fresh, drying dark brown to concolorous with blade; petiole 10 – 54 mm long, slender, not exceeding 0.5 mm in diam. in dried material, terete but longitudinally ridged, lacking a differentiated upper channel, concolorous with leaf upper surface to paler and browner, pulvinii when fresh pale green, indistinguishable when dry, central part concolorous with stem or paler. *Inflorescences* 1 per axil, spiciform, pendent; male inflorescences borne in axils of leaves that do not exceed c. 1 cm long (in early development) and appear grey-brown due to pubescence, axis to 155 mm long (including 3 – 11 mm long peduncle), slender like petiole, angled, bearing spirally arranged, irregularly spaced dense cymules of 2 – 8 flowers, rarely a solitary flower, subtended by a 1.4 – 2.1 × 0.4 – 0.6 mm, elliptic-acuminate cymule bract, each node of cymule with a 0.9 – 1.3 × 0.2 – 0.4 mm floral bract, similar to cymule bract but narrowly elliptic-acuminate to linear. *Male flowers* purple, shallowly bowl-shaped, on 0.2 – 1.1 mm long pedicels that are swollen immediately below torus, the latter 0.6 – 0.8 mm in diam., shallowly concave, opaque when dry; tepals 6, outer whorl weakly differentiated (slightly narrower), ovate to elliptic or broadly so, free, inserted on torus margin, ascending, upper half recurved at anthesis, translucent except midrib, apex rounded to

acute, sometimes cucullate, outer tepals 1.1–1.3 × 0.5–0.8 mm, inner tepals 1.0–1.3 × 0.6–0.9 mm; stamens inserted on torus margin, erect, filaments 0.05–0.1 mm long, stout, anthers 0.25–0.35 × 0.25–0.35 mm, broadly oblong-orbicular, basifixed; pistillode 3 ridges at torus centre at 120° to each other, c. 0.2 mm in diam. × 0.05 mm high. *Female inflorescences* unknown. *Infructescences* 38–135 mm long, peduncle 8–30 mm long, axis colour as stems. *Capsule* 23–28 × 15–19 mm, ascending at c. 75° to axis at dehiscence on recurved pedicels, obovate to oblong-obovate in outline, base rounded to truncate, apex obtuse to weakly retuse, styles persistent as a lobed apiculus, dehiscing from apex, immature capsule not seen, (sub)mature with wing thickness not exceeding 1 mm, not fleshy, pale straw-brown with red-brown markings, when mature each wing single-layered, uniformly pale to mid brown or speckled with darker brown or grey-brown when dry. *Seed* winged at base only, 5.6–8.0 × 3.4–5.1 mm (excluding wing), obovate in outline, dark brown, base rounded to acute, apex obtuse to rounded, wing 5.7–11.2 × 5.2–6.7 mm, papery and translucent chestnut brown. Figs 1, 2.

RECOGNITION. Tuber horizontal in soil with a curved apex (derived from digging up two plants and inferring a similar position in others from the shape of extraction holes and the Malagasy vernacular name). Leaves in clusters of up to 7 on short herbaceous branches, clustered particularly towards bases of main vegetative stems (Fig. 1A, 2B), blades thin in texture, densely pubescent below and when immature but coarse and never forming a tomentum as in *Dioscorea ovinala*. Plants at the locality near Irodo represented by Wilkin *et al.* 1674 and 1675 often have white spotting on their leaf blades which has the appearance of pathogenic infection (see Fig. 2A). Male inflorescences (Fig. 1 E, F) with irregularly spaced, spirally arranged dense cymules of 2–8 pedicellate flowers or rarely solitary, vs flowers (sub)sessile, or rarely with a pedicel to 0.5 mm long and solitary or in groups of 2–4 (*D. ovinala*). Fruit not inflated and fleshy during development but thin-lobed and capsular throughout, single layered at dehiscence. Restricted to a small area East of Sadjoavato in Antsiranana Province.

DISTRIBUTION AND HABITAT. Endemic to the Irodo river Valley and Sahafary forest in Antsiranana Province (Map 1) at altitudes from 30–230 m. It is possible that the three collections from South of the village of Irodo represent two subpopulations on either side of the river as opposed to two distinct populations (the term population is used here in an ecological sense, except in the Conservation Status section), but the specimen from Sahafary forest is spatially isolated. At Irodo, it is found in semi-deciduous forest with a canopy to 10 m and a clear shrub layer, the principal canopy trees being *Colvillea* and *Tamarindus*, with *Pachypodium* in the shrub layer. Soil a brown sandy loam, possibly alluvial, or red

sand over limestone bedrock. The Sahafary Forest specimen states that it was from scrub forest on red sand.

SPECIMENS EXAMINED. MADAGASCAR. Antsiranana Province: Sahafary Forest, Analakay Forest, E of National Route #6, 12°35'03"S 49°25'08"E, ♂ fl. & ♀ immat. fr., 8 Nov. 2006, Z. S. Rogers, R. Ranaivojoana, C. Davidson, S. R. Christoph & F. Ratov 1149 (K!, MO); Analamera, bank of Irodo R., near Irodo camp, 12°40'25"S 49°32'40"E, ♀ immat. fr 6 Jan. 2002, P. De Block, F. Rakotonasolo & T. Randriamboavonjy 1079 (BR, K!, K000523804); Diana, Antsiranana II, Anivorano, Irodo, *ala fady* S of village towards Irodo river estuary, 12°39'6.2"S 49°31'37.9"E, old ♂ fl. 8 Feb. 2015, P. Wilkin, J. A. Kennerley, F. Rakotonasolo, M. Hamido & M. Tsaratiana 1674 (K!, TAN!).

CONSERVATION STATUS. The specimen data cited above and field surveys to date suggest that *Dioscorea irodensis* occurs at no more than three localities. *D. irodensis* is only known to be extant at one locality south of Irodo village on the banks of the Irodo River, where it was found in 2015 and 2016 (see Map 1). It has not been possible to cross the Irodo River during field activity in 2015 and 2016 to survey the subpopulation represented by the 2002 specimen (*De Block et al.* 1079). In March 2016, a field team spent a day locating the coordinates of the Sahafary forest specimen (*Rogers et al.* 1149) and searching other suitable habitat in Sahafary forest. The specimen was collected in highly degraded vegetation on the edge of a *Eucalyptus* plantation. No plants of *D. irodensis* were seen anywhere in Sahafary. If present they would certainly have possessed above ground organs in March, thus the subpopulation has either been eradicated through habitat degradation and loss or there is an error in the GPS coordinates, perhaps caused by use of an older GPS model. For the present we must assume the former. It is likely that the subpopulation represented by *De Block et al.* 1079 is extant given its isolated location, so we recalculated EOO and AOO excluding only the Sahafary forest data point. This gave an EOO of less than 1 km² and AOO of 8 km² based on a standard cell width of 2 km. Both are below the CR threshold.

In addition to habitat loss and restricted EOO/AOO, *Dioscorea irodensis* appears to be threatened by limited population size and extraction for use as food. At the site where it known to be extant, 10 adult plants were seen in 2015, of which 4 were female, and 15 in 2016, of which 5 were female. There is a limited reservoir of juvenile plants and a much more substantial one of seedlings with one or two leaves. A conservative estimate of generation length is 10 years; this is based on the authors' experience of cultivating wild *Dioscorea* species from Madagascar from seed. Thus it could be 8 or 9 years before seeds are produced by plants that are currently juveniles or seedlings. We are in the process of acquiring data on the abundance of these life history stages via plot surveys. Approximately 80 seeds were collected for banking by the Millennium Seed Bank Partnership in March 2015. The sacred forest in which the subpopulation is found has an estimated 100

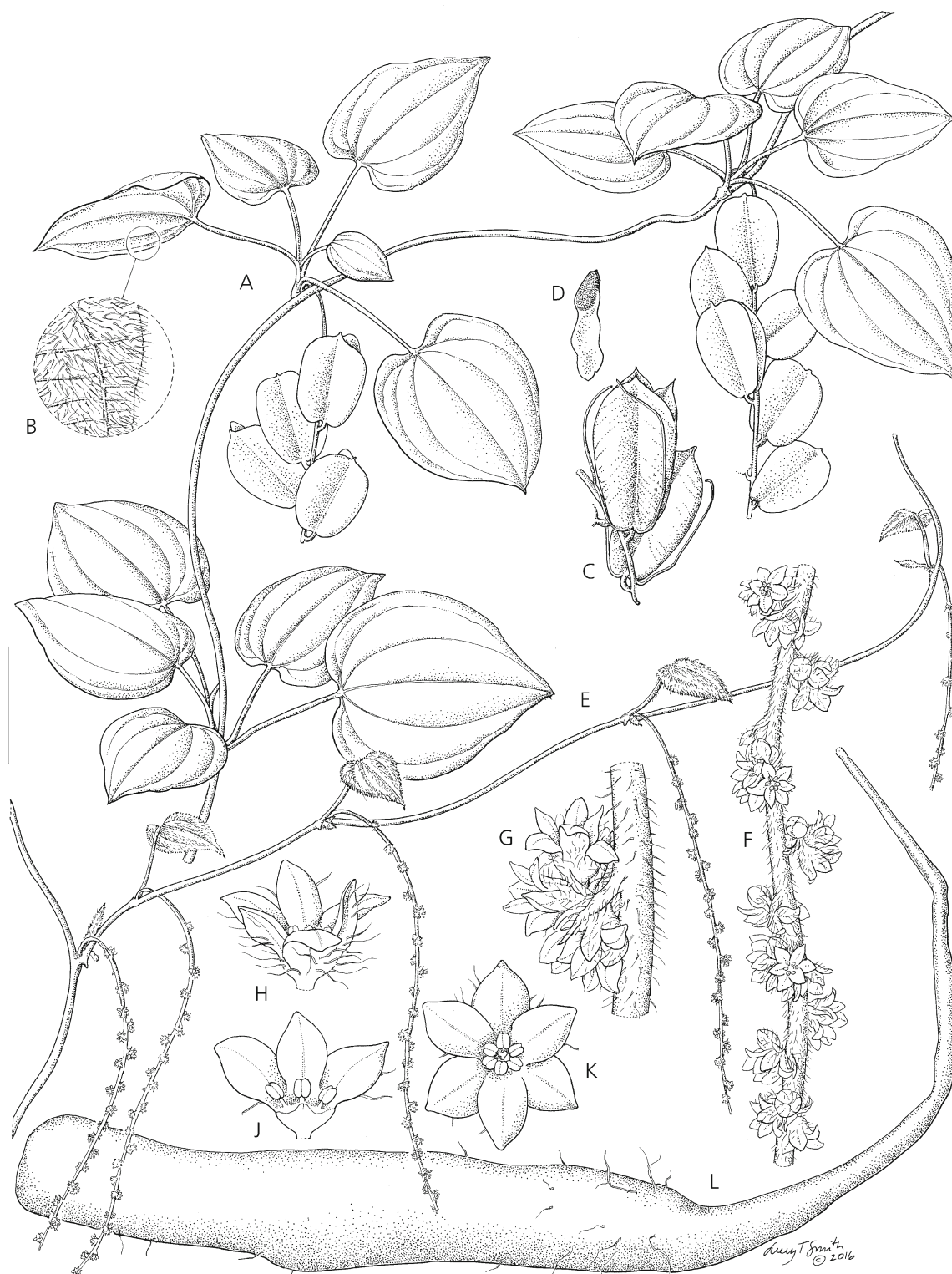


Fig. 1. Vegetative and reproductive organ morphology in *Dioscorea irodensis*. **A** habit of fruiting plant, showing leaves borne in clusters of up to 7 on short herbaceous branches; **B** detail of coarse, erect to spreading indumentum; **C** dehiscent capsule; **D** seed and seed wing; **E** habit of male flowering plant with leaves in early development; **F** part of a male inflorescence showing condensed cymules of flowers; **G** a single cymule showing the cymule bract and inflorescence axis indumentum; **H** side view of a male flower showing pubescent tepal external surfaces; **J** half male flower showing three stamens, torus morphology and pistillode; **K** flower viewed from above showing inner and outer tepal whorls and anther presentation; **L** tuber drawn following its usual orientation in the soil and curved apex that subtends a shoot. Scale bars: **A**, **E** = 2.5 cm; **B** = 5 mm; **C**, **D** = 2 cm; **F** = 4 mm; **G** = 2 mm; **H** – **K** = 1.5 mm; **L** = 6 cm. DRAWN BY LUCY SMITH.



Fig. 2. Photographs of *Dioscorea irodensis* showing its vegetative morphology in fruit and underground organs. **A** leaves and an inflorescence reduced to a solitary submature capsule; **B** node with a cluster of leaves on a short lateral shoot showing an infructescence at dehiscence; **C** two tuber apices (current (marked a) and previous year (b)) and separated body of current year's tuber (c) with stem and leaves disentangled from surrounding vegetation. The size and curved apex of the tuber (indicated by arrows) linked to its horizontal habit is shown.

yam extraction holes, of which at least 20 appear to have been made within the last 12 months. Whilst timber extraction from the forest is culturally forbidden, removal of non-timber forest products is not. It is likely that any undiscovered subpopulations face a similar level of extraction which appears to be unsustainable. The village of Irodo has recently agreed to join the Darwin Initiative-funded project “Conserving Madagascar’s yams through cultivation for livelihoods and food security”. The principal shared goal will be to conserve *D. irodensis* and *D. maciba* Jum. & H. Perrier through cultivation alongside the winged yam *D. alata* L. The productivity of the latter should drive down demand for wild-harvested yams. We will also collect further seed for banking and duplicate living accessions elsewhere as far as possible.

In accordance with IUCN (2001) criteria, these data and observations suggest *Dioscorea irodensis* should be designated as CR A2acd+4acd; B1ab(i, ii, iii, iv, v)+2ab(i, ii, iii, iv, v); C1+2a(i); D (Kennerley & Wilkin, *in prep.*).

ETYMOLOGY. Named for the village of Irodo and the Irodo River valley where this species is found.

VERNACULAR NAME. *Bemandry* in the village of Irodo. This name appears to be applied particularly to species with horizontal tubers, for example the element of *Dioscorea soso* Jum. & H. Perrier *sensu lato* with the same tuber habit.

USES. Tuber edible cooked. Rather watery following cooking and thus not fully satisfying the appetite. *Dioscorea maciba*, known as *batatala* in Irodo, is the more sought after species of the two that are found in the Irodo valley and surrounding areas. Not believed to be sold in markets but consumed usually in March/April.

NOTES. The specimen *de Block et al.* 1079 was included within *Dioscorea sambiranensis* subsp. *bardotiae* Wilkin by Wilkin *et al.* (2009) as an atypical element. Its removal to *D. irodensis* restricts the known distribution of *D. sambiranensis* subsp. *bardotiae* to the Montagne des Français (just one specimen) and the Réserve spéciale d’Ankarana and surrounding limestone outcrops. The resulting reduction in EOO and AOO is likely to increase the threatened status of that subspecies from Vulnerable (Wilkin *et al.* 2009) to Endangered and this is confirmed by recent unpublished EOO and AOO results obtained from GeoCAT.

Acknowledgements

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munity joining those engaged in the Darwin Initiative project with a view to conserving *Dioscorea irodensis* (*Bemandry*) and *D. maciba* (*Batatala*) together. Thanks are also due to Madagascar National Parks in Anivorano, especially M. Hamido, Mr Ramiandrarivo Liva Hariniaina, Directeur des Aires Protégées Terrestre (DAPT) — Ministère de l’Environnement, de l’Ecologie, de la Mer et des Forêts (MEEMF) for issuing collecting permits, and Mr Zafimandimby, Chef Cantonnement in Ambilobe for their help. Finally, we thank Steve Bachman for his input into the conservation status assessment and Dr Hélène Ralimanana, Dr Franck Rakotonasolo, Landy Rajaovelona, Hajatiana Rakotoarimanana, Roger Rajaonarison and Joel Rakotonirina for their facilitation of this research, and the anonymous reviewers who helped to improve the manuscript

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