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Rafflesia verrucosa (Rafflesiaceae), a new species of small-flowered *Rafflesia* from eastern Mindanao, Philippines

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Abstract

The new parasitic plant species *Rafflesia verrucosa* from Mt. Kampalili in eastern Mindanao (Philippines) is described, bringing the total number of Philippine *Rafflesia* to ten. *Rafflesia verrucosa* is the first small-flowered *Rafflesia* described from Mindanao Island, and differs notably from similar-sized species by the dense and prominently raised warts on the perigone lobes and diaphragm, the cup-shaped disk ornamented with dense pubescence on the abaxial surface, in the anther sulci and corona extending to the basal third of the disk exterior, the pleated, laminar and interconnected processes, the toroid annulus, and the extremely small and more numerous (20 or 21) anthers. Like *R. baletei* of Luzon, this new species has bisexual flowers. *Rafflesia verrucosa* is the third species found in the island of Mindanao where it occurs in montane forest from ca. 1300–1550 m., an exceptionally high elevation range for Philippine *Rafflesia*. It has the smallest flowers on average in the genus.

Key words: Mount Kampalili, eastern Mindanao, parasitic plants

Introduction

Rafflesia Brown (1821: 207; Rafflesiaceae) is a genus of endophytic holoparasitic plants growing in species of the liana genus *Tetrastigma* (Miquel 1863: 72) Planchon (1887: 423; Vitaceae) in tropical forests of Indonesia, Malaysia, the Philippines and Thailand. In his book on *Rafflesia*, Nais (2001) recognized 18 species, of which two, *R. manillana* Teschemacher (1844: 65) and *R. schadenbergiana* Göppert ex Hieronymus (1885: 3) are from the Philippines. Nine additional currently accepted species of *Rafflesia* have been described since Nais' landmark work. Seven of these are found in the Philippines (Barcelona & Fernando 2002, Fernando & Ong 2005, Barcelona *et al*. 2006, 2008, 2009a, Galang & Madulid 2006, Madulid *et al*. 2007; reviewed in Barcelona *et al*. 2009b), one was described from Sumatra (*R. bengkuluensis* Susatya, Arianto & Mat-Salleh 2006: 147), and one from Peninsular Malaysia (*R. azlanii* Latiff & Wong 2003: 137). These recent discoveries more than quadrupled the total number of known Philippine *Rafflesia* in less than a decade. Of the Philippine species, five are found in Luzon (*R. aurantia* Barcelona *et al.* (2009a: 18), *R. baletei* Barcelona *et al*. (2006: 232), *R. leonardi* Barcelona *et al.* (2008: 224), *R. manillana* and *R. philippensis* Blanco (1845: 565)), one in Samar (*R. manillana*), two in Panay (*R. lobata* Galang & Madulid (2006: 2) and *R. speciosa* Barcelona & Fernando (2002: 648)), one in Negros (*R. speciosa*), and two in Mindanao (*R. mira* Fernando & Ong (2005: 267) and *R. schadenbergiana*; Fig. 1). The previously known Mindanao species have the largest flowers among Philippine *Rafflesia*.

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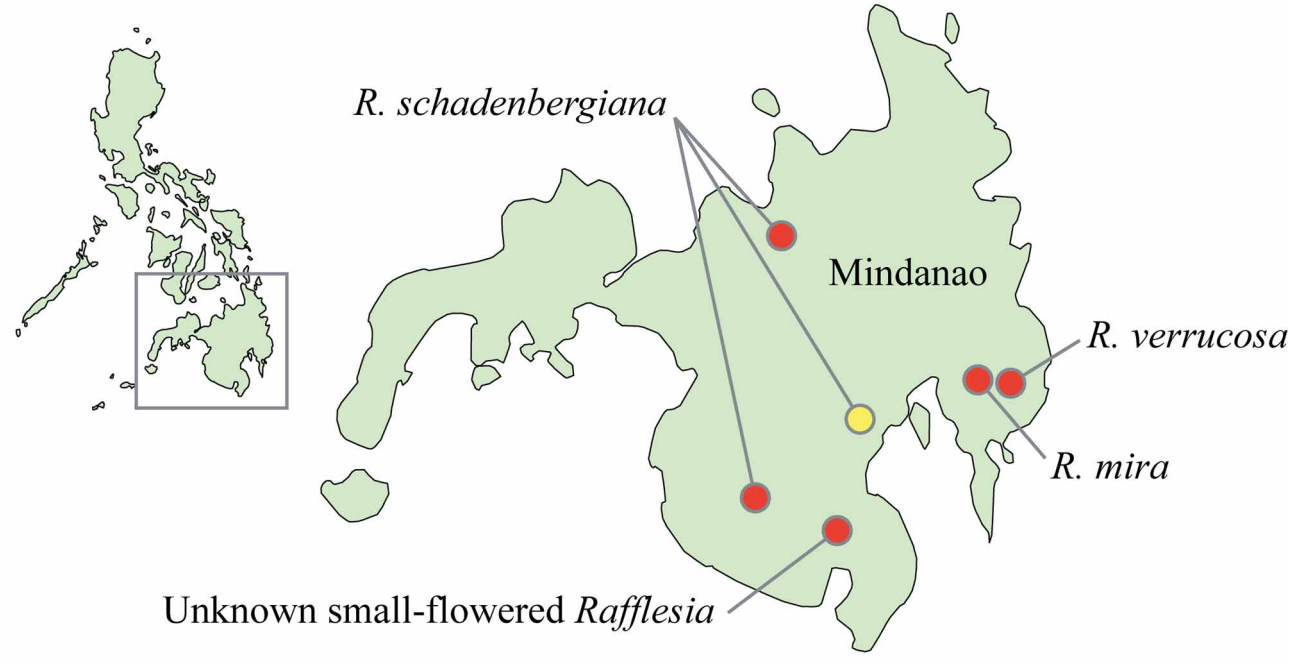

FIGURE 1. Location of known *Rafflesia* populations in Mindanao. Red circles: extant populations, yellow circle: historical population not observed in recent years.

In February and March 2010, during a joint Philippine Eagle Foundation – Field Museum small mammal survey of Mt. Kampalili in eastern Mindanao, we discovered populations of a highly unusual small-flowered *Rafflesia*. The morphological features of these populations require recognition as a new species, which is described below. This new discovery raises the number of Philippine *Rafflesia* species to ten.

Taxonomic treatment

Rafflesia verrucosa Balete, Pelser, Nickrent & Barcelona, sp. nov. (Figs. 2A–F, 3A–F)

Rafflesiae baleteae floribus bisexualis, et R. leonardae antheris numerosis, 20-21, etiam R. aurantiae formis ramentorum similis. Autem verrucis prominentibus in perigonio et diaphragmate orae aperturae attingentes, disco cupulato processibus laminaribus sinuosis consociatis confertim impletis, corona pubiscentia densa ad trientum basilarem disci externi extensa, annulo latissimo toroido relative laevi, antheris minimus numerosioris ab omnibus aliis rafflesiis parvis praesertim differt.

Type:—PHILIPPINES: Mindanao Island: Davao Oriental Province: Manay (also known as Man-ay) Municipality: Mt. Kampalili, 7.29112° N, 126.31520° E, 1470 m, 3 March 2010, *Balete 17* (holotype PNH, isotypes CAHUP, F, L, SING, US).

Endophytic holoparasite. *Mature buds* to 7.5 cm in diameter. *Cupule* 2.0 cm high to 6.0 cm wide. *Bracts* (or *bud scales*) numerous in three to four imbricate whorls, outermost smallest, ca. 1.6 cm long, 1.5 cm wide, innermost largest to ca. 5.1 cm long, 6.5 cm wide. *Flowers* 14.5–16 cm in diameter when fully expanded, 11.5–13 cm high (Fig. 2A), with a very mild putrescent smell when fresh. *Perigone tube* ca. 3.5–5.5 cm long, inner surface with minute pustules (broccoli-like), with a midlayer of sclerenchymatous tissue that extends to the perigone lobes, this persisting beyond senescence and into fruit maturity, often forming a cup-like structure on top of the maturing fruit (Fig. 2B). *Perigone lobes* 5, orbicular to broadly orbicular, 4.2–4.5 cm long, 6.5–8.0 cm wide, margins irregularly sinuate, reddish orange or cinnamon, becoming dark brown with age; adaxial surface verrucose, *warts* prominently raised, solitary, irregular in shape, size, and density, usually

roundish, less often rod-like to narrowly elongated, white-tipped in newly opened flowers, with age becoming concolorous with perigone adaxial surface, abscising upon flower senescence leaving a persistent wood-like tissue extending from the perigone tube (Fig. 2B); abaxial surface covered with hardened tissue that is

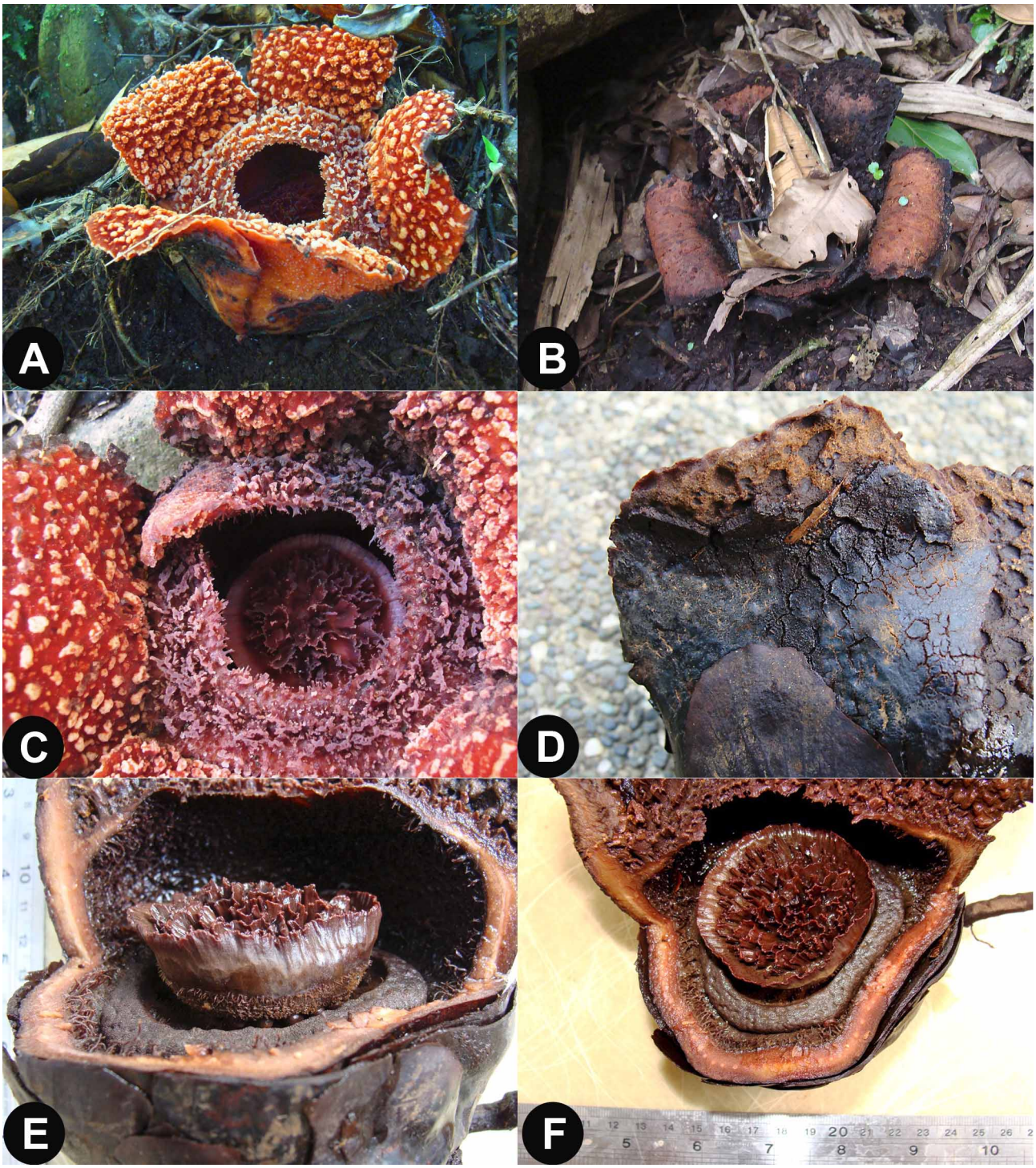

FIGURE 2. A. Newly-opened flower showing verrucose perigone lobes and diaphragm. **B.** Senescent flower showing persistent sclerenchymatous perigone tissue after warts have fallen off. **C.** Close-up of the diaphragm and perigone showing dense and prominently raised warts. **D.** Abaxial surface of the perigone lobe revealing pitted surface beneath corky, cracking and flaking outermost tissue. **E.** Section through the floral perigone tube showing internal components including the acicular hairs ornamenting the exterior basal 1/3 of the cup-shaped disk, the laminar, interconnected processes of the disk, and the shallowly rugose annulus. **F.** Top view of the perigone tube interior showing the disk, its processes, and the annulus. **A, D–F.** Holotype, *Balete 17*. **C.** *Balete 18*. **D–F.** Specimens in spirit.

irregularly cracked and partially flakes off (sometimes already early in the development of the flower) revealing a pitted inner layer (Fig. 2D). *Diaphragm* 7–9 cm in diameter, 2–3.5 cm wide from aperture rim to base of perigone lobes, 9–11 mm thick at base, becoming thinner towards the aperture; concolorous with or slightly darker than the adaxial perigone surface; densely covered with prominently raised, pleated, plate-like warts that are white-tipped in newly opened flowers, these variable in size, larger ones 3–8 mm tall, intermixed with smaller ones, ca. 1–2 mm tall (Fig. 2C); windows absent; aperture 3.5–4 cm in diameter. *Disk* 5–5.5 cm in diameter, ca. 1–1.2 cm thick midway between the margin and the point where the disk joins the column, cup-shaped with a prominently raised margin, concolorous with diaphragm; processes forming an interconnected system of tightly packed, laminar plates with erose margins, ca. 3–11 mm tall (Fig. 2C, E–F); *column* very short, up to ca. 1 cm from the floor of the floral tube to the upper surface of disk, ca. 2.3 cm wide, deeply grooved, number of sulci corresponds to the number of anthers, septa between sulci ca. 1 cm tall, with acicular hairs ('bristles' sensu Nais 2001) ca. 1.5 mm long; *annulus* ca. 7–10 mm wide, ca. 5–6 cm in diameter, doughnut-shaped (toroid), concolorous with the rest of the perigone tube, surface shallowly pitted and rugose (Fig. 2F). *Ramenta* to 7 mm long, covered with clavate pustules, polymorphic, filiform to variously branched or cleaved apically, those at the floor of the perigone tube longer and denser becoming shorter and more widely spaced on the diaphragm, nearly absent near the aperture rim, white-tipped in newly opened flowers, becoming concolorous with perigone abaxial surface with age. *Flowers* bisexual (Fig. 3A); *anthers* 20 (or 21), globular, ca. 2 mm in diameter, prominently protruding from very shallow anther sulci that are 2–3 mm long, 3–4 mm wide (Fig. 3B), basal third of disk formed into a pubescent corona with bristle-like, acicular hairs to 0.5 mm (Fig. 2E, 3B); *ovary* ca. 1.5 cm tall, 4.5 cm wide, lenticular or reniform, becoming broadly and irregularly so as the ovary matures (Fig. 3C); developing fruits to 7 cm in diameter and 4.7 cm high, sclerenchymatous perigone tissue persistent.

Distribution and habitat:—*Rafflesia verrucosa* is only known from the southeastern slope of Mt. Kampalili, Davao Oriental Province, Mindanao Island (Fig. 1). It is found between 1350 and 1550 m. Despite extensive search efforts in the area, it was not encountered at lower (900–1350 m) or higher (1550–1700 m) elevation, although the presence of *Tetrastigma* vines, which is the host for this species, was confirmed throughout the elevational range explored.

The habitat of *R. verrucosa* is montane forest in relatively rocky and moderately sloping terrain. Leaf litter is ca. 2–5 cm thick. The canopy is ca. 15 m tall and emergents reach 20 m. The larger trees in this forest commonly reach a DBH up to ca. 90 cm. Dominant trees are oaks (*Lithocarpus* Blume 1826: 526), laurels (*Litsea* Lamarck 1792: 574), and myrtles (*Syzygium* Gaertner 1788: 166). Mosses are common on tree trunks and branches, and often also at the bases of trunks. Other epiphytes include ferns and lycophytes, *Medinilla* Gaudichaud-Beaupré (1830: 484), and orange-flowered *Rhododendron* Linnaeus (1753a: 392). Understory vegetation is abundant and composed of tree ferns, other ferns and lycophytes, ground orchids, gingers and grasses. Canopy vines such as *Freycinetia* Gaudichaud-Beaupré (1824: 509), climbing bamboos, rattans, *Smilax* Linnaeus (1753b: 1028), *Tetrastigma*, and other lianas are likewise common. Several *R. verrucosa* plants were found on *Tetrastigma* vine roots growing exposed on rocky ground which resulted in deformed buds and flowers.

Etymology:—The specific epithet of this new taxon is derived from the Latin *verruca* (wart), which calls attention to the unique, prominently raised warts on the perigone lobes and diaphragm.

Ecology:—*Rafflesia verrucosa* is restricted to plants of a single, presently unidentified species of *Tetrastigma* (Fig. 3D, specimen not collected). Flowers and buds were only observed on the roots of their host plants and are absent on prostrate and aerial stems. *Tetrastigma* roots bearing *Rafflesia* flowers or scars range from 6 to at least 25.5 mm in diameter and buds were found on roots buried up to 7 cm below ground level.

A total of 15 clusters of flowers and buds were discovered in an area of ca. 20 m × 1 km. At one site, at least 30 *Rafflesia* buds in different stages of development as well as senescent flowers were observed (Fig. 3E). This is equivalent to ca. 7–8 flower clusters per hectare. At the time of discovery of *R. verrucosa* (February–March, 2010), a notably large number of senescent flowers and developing fruits were observed. This suggests that flowering must have peaked around October to December similar to what is reported for *R.*

mira, a species found in the adjacent Mt. Candalaga, Compostela Valley (Madulid *et al*. 2006). Since some mature buds, newly opened flowers, and early senescent flowers were also observed during our visit in February–March, flowering appears to continue intermittently throughout the year.

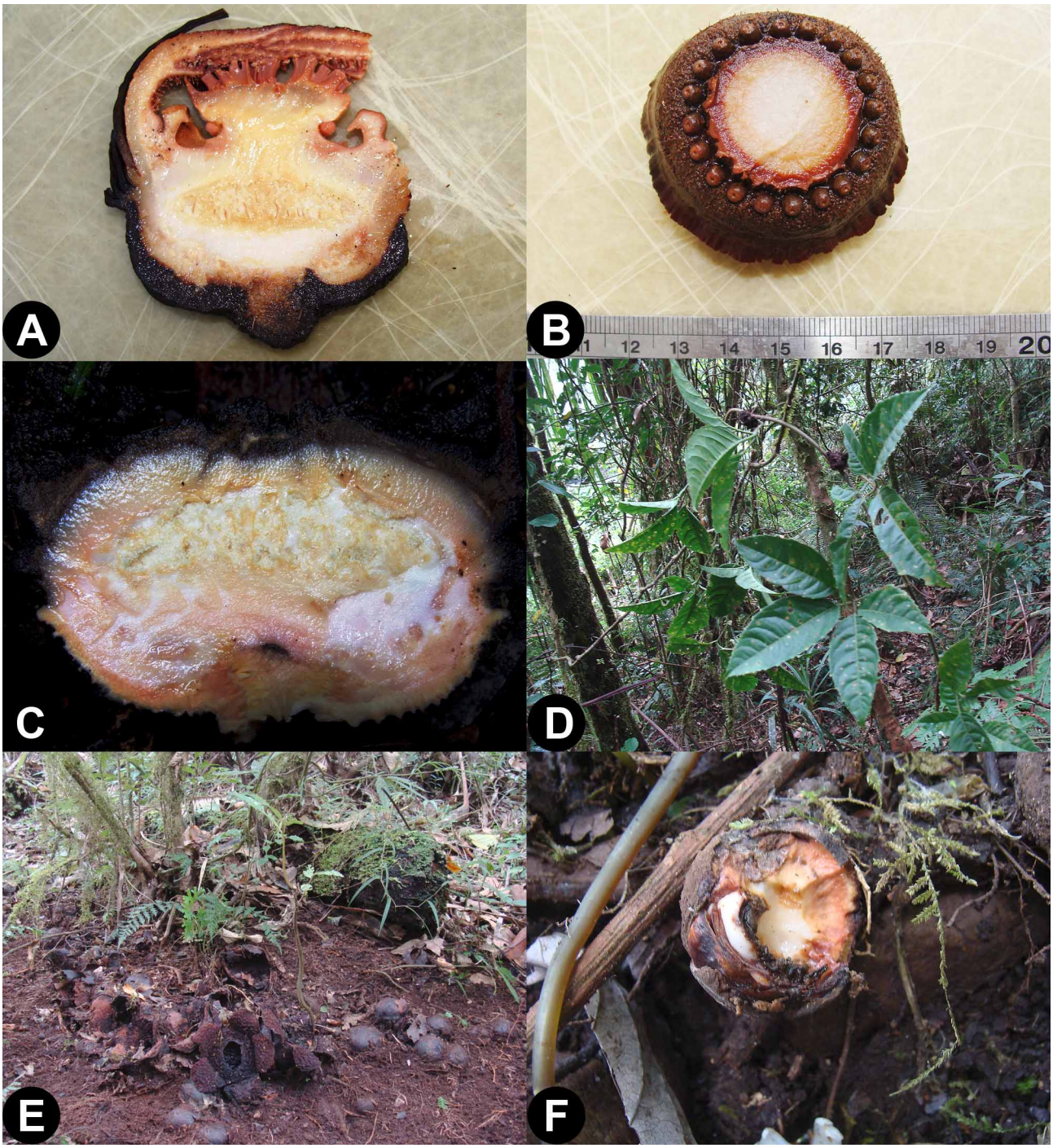

FIGURE 3. A. Longitudinal section through a bud showing both anthers and ovary. **B.** Cross section through the column neck showing undersurface of disk with anthers in shallow, pubescent sulci, and corona. **C.** Longitudinal section through an early developing fruit showing slightly lunate ovary. **D.** *Tetrastigma* sp., host of *R. verrucosa*. **E.** Partially cleared area exposing clusters of buds and senescent flowers attached to the roots of a single host plant. **F.** Immature bud showing signs of predation. **A.** *Balete 18*. **B.** Holotype, *Balete 17*. **A–B.** Specimens in spirit.

Several buds as well as a maturing ovary of a senescent flower showed evidence of damage by animals, mainly as bite marks of unidentified small-toothed mammals (Fig. 3F). Systematic trapping in the area where

R. verrucosa occurs yielded at least ten species of native non-volant small mammals, including a gymnure (*Podogymnura*), a shrew (*Crocidura beatus*), a tree shrew (*Urogale everetti*), two shrew-mice (*Crunomys*), a moss-mouse (*Tarsomys*), an arboreal tree-mouse (*Apomys*), a forest mouse (*Apomys*), the large Mindanao forest rat (*Bullimus bagobus*) and the common Philippine forest rat (*Rattus everetti*). Also reported in the area by local hunters are two species of squirrels (*Exilisciurus concinnus* and *Sundasciurus philippinensis*). Likewise, we also documented the presence of larger mammals, including palm civet (*Paradoxurus hermaphroditus*), Philippine warty pig (*Sus philippinensis*) and Philippine brown deer (*Cervus mariannus*). At ca. 1500 m, wild pig diggings on the ground around three populations of *R. verrucosa* are extensive but no sign of feeding on the buds and flowers was observed, although several were trampled upon. The role of these mammals in *Rafflesia* dispersal in the Philippines remains unstudied. But in Borneo, for instance, both squirrels (*Callosciurus*) and tree shrew (*Tupaia*) are known to feed on *Rafflesia* fruits (Emmons *et al.* 1991).

Conservation:—*Rafflesia verrucosa* plants grow in the tropical montane forest formation (Fernando *et al.* 2008) which is increasingly undergoing disturbance and fragmentation from clearing for abaca (*Musa textilis* Née 1801: 123) plantations by native Mandayas. In addition, trees in the area are cut to harvest the young palm heart of the rattan plants that climb these trees. This practice resulted in areas of up to 100 m^2 in which tall trees have been cleared and the understory has been damaged. Despite this disturbance, the forest of the Mt. Kampalili Range is relatively intact and certainly does not suffer from the same degradation and loss that plague the lowland forest in which the majority of the Philippine *Rafflesia* are found (Barcelona *et al.* 2009b). Although *R. verrucosa* is moderately common in the area, it is not known from any other site on Mt. Kampalili or elsewhere and we therefore recommend that the clearing of the forest for abaca plantations and the harvesting of other forest products must be carefully managed in the wider area to ensure the continued survival of this new species of *Rafflesia*. We strongly support efforts by local people (e.g. Taocanga Tribal Council Association), environmental organizations (e.g. Philippine Eagle Foundation) and concerned government agencies (e.g. Department of Environment and Natural Resources and the Department of Tourism Region XI) to place certain portions of Mt. Kampalili under protected area and ancestral domain management.

Additional specimens examined (paratypes):—PHILIPPINES: Mindanao Island: Davao Oriental Prov., Manay (= Man-ay) Municipality: Mt. Kampalili, 7.29796°N, 126.31216°E, ca. 1378 m, 25 February 2010, *Balete 16* (SING); 7.29537°N; 126.31606°E, ca. 1550 m, 1 March 2010, *Balete 18* (PUH, US).

Discussion

Rafflesia verrucosa is the first small-flowered *Rafflesia* species described from Mindanao. The two other currently accepted species from the island, *R. mira* and *R. schadenbergiana*, rank amongst those with the largest flowers in the genus (*R. mira*: 45–60 cm in diameter; *R. schadenbergiana*: 52–80 cm in diameter). The flowers of this new species are significantly smaller (14.5–16 cm in diameter) and are the smallest in average size for the genus.

Rafflesia verrucosa further differs from other known *Rafflesia* species in several other morphological characters, most notably by the prominently raised warts on the perigone lobes and diaphragm. The warts on the perigone lobes are unusual in their shape, size, density and deciduous nature. Warts on the diaphragm are also unusual in their size (large and small) and shape (pleated, plate-like). The diaphragm aperture rim is erose and in places, shaped like the larger warts. This is in contrast with the wartless diaphragm rim of all other *Rafflesia* species. The plate-like, anastomosing disk processes also differ from those of all other species. These usually have peg-like (*R. manillana*), spike-like (many *Rafflesia* species such as *R. speciosa*), or solitary blade-like (e.g. *R. mira*) processes. Some species have poorly developed processes, which may sometimes even be entirely lacking (e.g. *R. leonardi* and *R. rochussenii*). Additionally, the ramenta are longer (up to 7 mm) than those of all other small flowered *Rafflesia* except *R. aurantia* (7–10 mm) and are covered with minute, clavate, epidermal excrescences. The anther number (20 or 21) is greater than those of all other similar-sized Philippine *Rafflesia,* but similar to *R. leonardi* of Northern Luzon, a species with flowers that are

twice as large as *R. verrucosa*. These extremely small anthers (ca. 2 mm) are packed beneath a relatively small disk. The basal third of the disk is densely pubescent and this extends to the undersurface (the corona) and to the area surrounding the anther sulci, all features unique to *R. verrucosa*. Finally, the presence of the sclerenchymatous tissue in the perigone lobes and tube and its persistence through flower senescence and fruit formation is unique among *Rafflesia* species.

Rafflesia verrucosa is not only unique in its morphology, it is also the first species in the Philippines found growing only in montane forests at elevations between 1350 and 1550 m. All other species of *Rafflesia* in the Philippines occur in lowland dipterocarp forest or forest over limestone below 1000 m, rarely extending up to 1270 m in transitional lowland/lower montane forest (Barcelona *et al.* 2009b). Also *R. rochusennii* of Java and Sumatra and *R. pricei* of Sabah have populations that reach 1500 m. Their elevational range is, however, much wider than *R. verrucosa*, extending to the lowlands at ca. 700 m and 400 m, respectively (Nais 2001). At our current level of knowledge, it is impossible to say if the elevational limits of *R. verrucosa* are due to range limits of pollinators or dispersal agents, environmental effects, the range of a particular species of *Tetrastigma*, or happenstance.

Although *R. verrucosa* is the first named small-flowered *Rafflesia* species from Mindanao, a small-flowered *Rafflesia* has previously been collected on Mt. Matutum in south central Mindanao (Barcelona *et al.* 2006, 2007, 2009b). This specimen is unfortunately too deteriorated to establish its taxonomic identity (Barcelona *et al.* 2009b).

A molecular phylogeny is being prepared for Philippine *Rafflesia* by the coauthors, but at the time of this writing *R. verrucosa* DNA was not available for analysis. Despite this, its unusual morphology raises questions about potential phylogenetic affinities among *Rafflesia* species. Cladistically, *R. verrucosa* shows a number of character states not observed in other *Rafflesia* species (i.e., autapomorphies). These include 1) wart morphology, 2) wart abscission from the adaxial perigone surface, 3) perigone lobe sclerenchymatous inner tissue, 4) cracking and abscission of the adaxial perigone surface, 5) perigone lobe persistence through fruiting, 6) elaborate warts on the diaphragm surface and rim of the aperture, and 7) a pubescent disk base. Without experimental or observational evidence, it is difficult to speculate as to any adaptive roles these features play in the life history of the parasite.

Among all species in the genus *Rafflesia*, bisexual flowers have only been reported for *R. baletei* (Barcelona *et al*. 2006, 2009b) and now *R. verrucosa*. It remains to be demonstrated however, whether either or both species are functionally bisexual. These data update Nais (2001) who stated that no evidence exists for hermaphroditic flowers in *Rafflesia*. Bisexual flowers are known in the genus *Rhizanthes* Dumortier (1829: 14), i.e. *R. zippelii* (Blume 1827: 422) Spach (1841: 554, see: Meijer 1997, Bänziger & Hansen 2000) and *R. lowii* (Beccari 1868: 198) Harms (1934: 287, see Bänziger *et al.* 2007), and this genus can be considered the sister group of *Rafflesia* (the third genus in the family, *Sapria* Griffith (1844: 216), has only unisexual flowers). Given the relationship of Rafflesiaceae to Euphorbiaceae and Peraceae (Davis *et al*. 2007), both with unisexual flowers, the most parsimonious assumption would be that the presence of unisexual flowers is the ancestral character state of all three Rafflesiaceae genera. But this scenario requires a reversion from unisexuality to bisexuality in *Rhizanthes* and two *Rafflesia* species, a very rare phenomenon in other flowering plants (Delph & Wolf 2005; Charlesworth 2006). Is it possible that ancestral Rafflesiaceae had bisexual flowers? Sexual expression in *Rafflesia* is still very poorly understood and genetic tools will be required to determine whether populations are polygamous, monoecious, dioecious, or even sequentially (temporally) dioecious. As pointed out by Endress (1994), dioecy is rarely absolute and sex changes can occur in some plants in response to environmental conditions and age. In any event, further investigation along these lines is warranted to better place Rafflesiaceae floral morphology in a phylogenetic context. For example, do the small, bisexual flowers of *R. verrucosa* indicate a relationship to *R. baletei* or do these represent yet another case of purported homoplasy in morphological characters for the genus (Barkman *et al.* 2008, Bendiksby *et al*. in press)? It is clear that *R. verrucosa* stands as one of the most unusual *Rafflesia* species described to date and that its further study will help illuminate numerous questions.

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