**Supplemental File 5.**

**Comments on character scoring and evolution in *Loranthus***

The Nexus file contained 21 morphological characters for 13 ingroup *Loranthus* taxa and one outgroup (*Cecarria*). A Branch and Bound search obtained 26 trees of length 48. The strict consensus of these trees gave a large polytomy for the ingroup whereas the majority rule consensus revealed more structure (Fig. 2). This tree is essentially congruent those obtained from analyses of the molecular data sets (Fig. 1). The molecular data strongly support a clade with *L. grewingkii* and *L. tanakae*, however, *L. europaeus* is not included.

The morphological data place this species in a polytomy with the clade of those two species and the remaining members of *Loranthus*. Placing *L. europaeus* with *L. grewingkii* and *L. tanakae* (making the Europaeus clade) does not change the overall treelength, thus this topology will be used for the discussion of characters below.

The characters used in these analyses are listed below. Those in red are discussed but not used (reasons provided). Characters 12-21 are continuous (log-transformed and standardized, see M&M) that were gap coded resulting in two or three states scored as 0 and 1 or 0, 1 and 2.

**Char. 1. Branching.** The Europaeus clade plus *L. lambertianus* all show pseudodichotomous branching. As with other mistletoes, true dichotomous branching does not occur (see Kuijt 2003, p. 10 for a similar situation in *Phoradendron*). The protologue for *L. grewingkii* (Bossier 1860) refers to the branching as divaricate-trichotomous. As indicated by observing herbarium specimens, ocassionally the central stem does not abort but continues growth beyond the two laterals. The branching in *L. guizhouensis* is of interest because some specimens are percurrent, others pseudodichotomous, and yet others a mixture of both types, with pseudodichotomous frequent in the distal branches. The morphology and molecular phylogenetic trees show the branch for this species occurs between the pseudodichotomous Europaeus clade and the percurrent Odoratus clade.

**Char. 2. Leaf arrangement.** In *L. europaeus* and *L. lambertianus*, leaf arrangement appears to be strictly opposite. In all other species, both opposite and subopposite arrangements can be seen. It should be pointed out that the arrangement of flowers on the inflorescence axis usually follows the leaf arrangement type (thus it was not scored as a separate character). For *L. grewingkii*, leaf arrangement is often difficult to discern because the leaves arrise as clusters from short shoots (brachyblasts). Overall, it seems that opposite, subopposite, and even alternate arrangements can be seen, the latter often on vigorous young shoots.

**Venation pattern and number of lateral vein pairs.** Attempts were made to use leaf venation features as characters, but without success. *Cecarria* has curvinerved venation whereas all *Loranthus* have some form of peninerved venation, sometimes with a basal lateral nerve approaching the curvinerved condition. The number of “pairs” of veins is sometimes used in descriptions, but this terminology is not appropriate because in many species the veins are not paired. Moreover, in some species venation is obscure. For proper comparison across all taxa, clearings should be made. The protologue for *L. odoratus* by Wallich (1824) indicates the leaves are veinless, which is not borne out by examining the type specimen.

**Char. 3. Leaf shape.** The shape of the leaf blade had the most states (9) of any of the characters analyzed and this required 25 steps for parsimony reconstruction. Nearly all taxa have combinations of two or more states. The outgroup *Cecarria* has a widely obovate leaf shape, a type not seen in *Loranthus*, and as such it provides no cladistic information. One possible trend may be the lance-ovate condition being frequently seen in the Obovatus clade. Another problem when reading descriptions of leaf shape in protologues or other literature sources is differences in application of shape terminology. For example, is there a difference between spatulate and narrowly obovate, or lanceolate and narrowly ovate? In some species different leaf shapes can be seen on developmentally different shoots. For example, in *L. lambertianus*, the lowermost leaves are obovate whereas the others are elliptic or lance-ovate. Overall, it is notoriously difficult to extract genus-level cladistic information from leaf blade shape.

**Leaf base.** In general, the bases of leaves across the *Loranthus* species show little variation. Most are basically cuneate (equivalent to acute for leaf apex), frequently also attenuate (sometimes described as decurrent). For these reasons leaf base was not used as a cladistic character because it is parsimony uninformative.

**Char. 4. Leaf apex.** Eight of the 14 taxa were coded as polymorphic for leaf apex, and this variation tends to cloud cladistic resolution (19 steps required). One apparent synapomorphy is the presence of a retuse and mucronulate leaf apex in *L. grewingkii* and *L. tanakae*.

**Char. 5. Inflorescence position.** Given the tree topology one might expect the outgroup *Cecarria* to have terminal inflorescences, but they are in fact axillary. Whether the inflorescence is terminal or axillary is one of the most important features for differentiating species groups in *Loranthus*. The character states map onto the phylogenetic trees such that the axillary state is a synapomorphy for the Odoratus clade. All other *Loranthus* species have terminal inflorescences. A very curious specimen, identified only as *Loranthus* (*Hyphear*) by D.G. Long is a specimen at Royal Botanic Garden Edinburgh (no. E00935373) from Kachin Hills, Myanmar collected by S. Toppin no. 4280. This plant clearly has both axillary and terminal inflorescences. Many of its features resemble the “*L. odoratus*” specimen collected by A.A. Bullock (no. 877) from the adjacent Manipur State, India. Unlike that specimen, its long inflorescences have not only open flowers but also what appear to be young fruits with persistent styles, thus suggesting the flowers could be bisexual.

**Char. 6. Inflorescence fascicles**. Fasciculate inflorescences occur in some of the taxa in the Odoratus clade. In *L. delavayi* and *L. kaoi*, fascicles are always present. In *L. pseudo-odoratus* the Flora of China description says “solitary or 2- or 3-fascicled”, thus indicating polymorphism. This is borne out by examining herbarium sheets where both conditions can be seen. For *L. odoratus* (the type), Wallich (1824) says “sometimes fascicled or sub-verticilled”. Examination of the type shows only solitary inflorescences. Further work is necessary to determine the distribution of this character across taxa in the *L. odoratus* complex.

**Flower pedicel.** The outgroup *Cecarria* can have either pedicellate or sessile flowers. It appears that all *Loranthus* species have sessile flowers, thus this character is parsimony uninformative.

**Char. 7. Inflorescence flower junction**. For the ingroup *Loranthus* species, there appears to be two conditions for the junction between the flower and inflorescence axis. For members of the Europaeus clade, the inflorescence axis protrudes upward into a cupule that bears the flower. For the remaining species, the flowers are sunken (to various degress) into inflorescence axis. This condition is referred to as foveolate, which means “pitted”. Actually, this pitting is best seen when the flower or fruit abscises, and that condition was illustrated for *L. guizhouensis*.

**Plant sexuality.** The majority of *Loranthus* species and the outgroup *Cecarria* are synoecious. Dioecy occurs in *L. delavayi*. The sexual condition for *L. europaeus* has been described as “subdioecious” meaning some individuals are female, some male, and other have male and bisexual flowers. These are the only two species that deviate from the synoecious condition, and they occur on different clades (Europaeus and Odoratus). For this reason, it is assumed they evolved independently. The protologue for *L. grewingkii* by Boissier (1860) states “floribus dioicus”, which, if interpreted literally says “flowers dioecious”. But dioecy is a whole plant condition, not an individual flower. The photos of this species indicate the flowers are bisexual.

**Bract features.** The sizes and shapes of bracts that subtend the flowers were not used, mainly because these small features require dissection and microscopic examination for proper interpretation and scoring.

**Mature flower bud shape.** Although this feature shows some variation and is used in descriptions, it appears to have limited cladistic value. Most species have clavate (club-shaped) floral buds. The degree of swelling of the apical portion of the bud compared to the tubular portion below varies considerable, hence some descriptions say “weakly clavate”. When the apex of the bud is not significantly different in diameter than the tubular portion, the bud is called cylindrical. For the species scored as polymorphic (e.g. *L. europaeus* and *L. delavayi*), the male flower is clavate whereas the female flower is cylindrical. The swollen apical portion can be attributed to the presence of anther sacs within. Detailed images are lacking of flower buds from either living or dried/pressed specimens positively identified as *L. lambertianus* but available information suggests they are clavate. The specimen tentatively identified as *L. lambertianus* (MD 1421, DLN 6752) clearly has clavate flower buds. Moreover, these buds show a distinctive oblique flattening of the apical swollen portion. This type of bud is also seen in a photograph of a mistletoe photographed in Bhutan by G. Glatzel. That plant, originally identified as *L. odoratus*, is more likely *L. lambertianus* given its terminal inflorescence and pseudo-dichotomous branching.

**Char. 8. Petal color**. Although flower color is frequently rather variable in plants (and of limited cladistic utility), in *Loranthus* corolla color shows some clear trends. The three species of the Europaeus clade all have greenish (green, light green, yellowish green) corollas. The only other member of the genus with this color is *L. guizhouensis* whose corolla color was scored based on the Flora of China description of “greenish”. No photos of living plants with mature, fully open flowers are available. In addition to pure white corollas, *L. odoratus* flowers have also been described as nearly white (the type from Nepal), cream (Manipur State, India) and yellow white (Myanmar). Whether these all represent the same species remains to be determined. The remaining species in the Lambertianus clade have yellow or yellowish corollas.

**Petal and stamen number**. The number of corolla lobes (petals) and stamens is always the same in *Loranthus*, thus these were not scored as separate characters. Although the outgroup *Cecarria* has 5-merous flowers, *Loranthus* is almost always 6-merous. Two exceptions occur. In *L. tanakae*, ocassional 5-merous flowers have been reported (Flora of China). The other report is from the protologue of *L. lambertianus* (Schultes 1829). Although the photo of the type specimen at BR shows one shoot with flower, there is insufficient resolution to determine merousity. The photo of the plant from Bhutan by G. Glatzel that is likely *L. lambertianus* is clearly 6-merous. In any event, flower merousity is parsimony uninformative.

**Petal shape.** Attempts were made to utilize the shape of petals (corolla lobes) as cladistic characters. Comparing descriptions to photos of living plants revealed the same problem encountered with leaf shape, i.e. that the actual shapes differed from the descriptions. Again, this is partly because these authors applied the terminology differently. For example, a number of authors used the term “lanceolate”, however, this term is ambiguous (can mean narrowly ovate or narrowly elliptic). From my observations, many of the petals appear to be narrowly oblong or narrowly obovate. Ovate petals are rare, possibly present only in *L. tanakae*. Ideally, petals from all species should be dissected and compared side by side to determine similarities and differences.

**Char. 9. Petals reflexed at anthesis.** Only three species do not have reflexed petals: *L. grewingkii, L. tanakae* and *L. kaoi*. The first two species are part of the Europaeus clade, hence this feature could be a synapomorphy. *Loranthus kaoi* is part of the Odoratus clade, thus the feature likely evolved independently in lineages derived from the shared ancestor of these taxa.

**Filament adnation to the corolla lobe.** There is clearly variation in this feature: fusion only at base of petal (e.g. *L. tanakae*), fused the entire length of filament (*L. grewingkii*), or fused 1/3 to ½ the length of the filament (the remaining species). This features was not used because the first two states are autapomorphic, thus contributing no cladistic information.

**Filament attachment to anther**. The outgroup *Cecarria* has dorsifixed, versatile anthers (a rare condition in Loranthaceae). All *Loranthus* have basifixed anthers, so this character is parsimony uninformative.

**Char 10. Anther locules.** This feature may be a synapomorphy between *L. grewingkii, L. tanakae*. It is also seen in *L. kaoi* which appears to be an independent derivation. [as an epiparasite, this more highly derived nutritional mode brings with it morphological reductions, as seen in *Arceuthobium* (Viscaceae), *Phacellaria* (Amphorogynaceae), etc.]. For *L. lambertianus*, the protologue by Schultes (1829) describes the anthers as “sat magnae, subrotundae, didymae, dorso affixae”, meaning “moderately large, subrotund, 2-lobed, dorsifixed”. As mentioned above, dorsifixed anthers are rare in Loranthaceae, so this must be an error. The two lobes might refer to the two thecae. But if this is a tetrasporangiate anther, then each theca has two sporangia (locules), meaning the entire anther has four locules.

**Staminodes and pistillodes.** In the subdioecious *L. europaeus* and dioecious *L. delavayi*, vestigial androecia (staminodes) and gynoecia (pistillodes) are present in the unisexual flowers. Because only these two species show these features, and they occur on different clades, it is assumed they evolved independently.

**Style articulation**. Only the outgroup *Cecarria* shows articulation in the style just above the base. None of the *Loranthus* species show this feature, hence it was not scored.

**Char 11. Fruit shape.** Only two states were used here, spherical (equivalent to globose) and ovoid. The latter also here includes ellipsoid. The fruit of *L. grewingkii* was described by Mehrvarz (2012) as obovoid, but this is not borne out by photos of living plants that show spherical fruits. The majority of *Loranthus* species have ovoid fruits. In addition to *L. grewingkii*, *L. tanakae* also has spherical fruits (a possible synapomorphy). There is no mention of the fruit in the protologue for *L. odoratus* by Wallich (1824). The character was scored as ovoid for this species based upon photos by G. Glatzel taken of a plant in Nepal. These fruits were immature (green), thus mature fruit color can not be ascertained.

**Fruit color.** Obtaining accurate data on the color of fruits is difficult for various reasons. First, not all observations recorded on herbarium labels take into account the fact that color changes as the fruit matures. Thus for descriptions of “green” fruits, it must be considered that they were immature. Also, different collections can vary. For example, with *Cecarria*, fruit color has not been included in any of the published descriptions, but information recorded on four herbarium sheets was as follows: first green, then orange; ripe berries yellow-orange; dull maroon green; glaucous. For this analysis, two states were used, white and yellow. Despite missing data, the reconstruction of this state on the tree shows yellow to be the predominant color. Only *L. grewingkii* has white fruits, so this character is parsimony uninformative. Shahi Shavvon et al. (2012) describe the fruit of this species as red, but apparently did not precisely translate the Latin from Boissier (1860) which said “baccis e sicco globosis rubris”, i.e. “berries spherical, red when dry”. Indeed, photographs of the fruits taken by G. Glatzel October 2018 shows mature, plump, ripe white fruits next to red desiccated fruits.

**Char. 12. Petiole length.** The mistletoes in clade Europeus generally had shorter petioles than those in clade Lambertianus. The one exception is *L. guizhouensis* which has comparatively shorter pedicels than other members of the Lambertianus clade.

**Char. 13. Leaf blade length**. A clear trend is seen where leaf blade size is larger in most members of the Odoratus clade compared with the other species. The exception is *L. kaoi* with smaller leaves. See comment under Char. 12 regarding morphological reductions in *L. kaoi*.

**Char. 14. Leaf blade width.** As with leaf length, width also shows a clear trend with members of the Odoratus clade have wider leaves than members of clade Europaeus. Again, the morphologically reduced L. kaoi is the exception.

**Char. 15. Inflorescence length.** The character was scored with two states, in general longer and shorter inflorescences. Most *Loranthus* have longer inflorescences whereas two taxa, *L. pseudo-odoratus* and *L. odoratus* (India 5) have shorter ones. Collections, not included in these analyses owing to limited data obtained from herbarium sheets, from eastern Indiam Myanmar, and Sulawesi, also showed these short inflorescences.

**Char. 16. Flowers per inflorescence.** This character is correlated with the previous one, however, its reconstruction on the tree reveals additional information. *Loranthus europaeus* and *L. grewingkii* of the Europaeus clade have 6-10 flowers per inflorescence. Other species generally have more than 10 flowers. The exception in this clade is *L. tanakae* which has 10-20 flowers. The other homoplasious species is *L. pseudo-odoratus* (Odoratus clade) with 4-6 (10) flowers.

**Mature bud length.** Although some variation occurs in this character, most species have buds ca. 3.0 mm in length, thus providing little cladistic information. One exception is a collection by A. A. Bullock (no. 877) from Minipur state, India. This specimen has large (5 mm) buds that have an extremely swollen apex (clavate). It can not be determined with certainty viewing only the herbarium sheet photos, but the flowers appear to be unisexual (male). It is possible this taxon represents a new species.

**Char. 17. Petal length.** In general *Loranthus* species have petals 2.5-5.0 mm long. The exceptions are *L. grewingkii* and *L. tanakae* that have significantly shorter petals (1.5-2.0 mm). The protologue for *L. odoratus* by Wallich 1824 says “corolla about three lines long”. Using the 1/12 inch conversion (2.11 mm) gives a corolla of over 6 mm, much longer than other species and the specimen from Nepal provided by M. Devkota. The bud length on the Wallich specimen at Kew (type) was measured. I then assumed that the bud length translates to petal length in the same way here as for the M. Devkota specimen.

**Char. 18. Filament length.** This character, with two states for the ingroup (outgroup *Cecarria* has much longer filaments, ca. 6 mm), separates the Europaeus and Lambertianus clades. For *L. guizhouensis*, the description in Qui et al. (2003, Flora China) is questionable. The filament length of 0.5 mm is probably just the free part, not including the part adnate to the petals. For *L. odoratus*, Wallich (1824) say “stamens shorter than petals”, but looking at the flowers of the M. Devkota specimen, the stamens are as long or longer than the petals.

**Anther length**. Essentially two types of anthers are seen in these mistletoes, large and small. The former occurs in the outgroup, *L. europaeus* and *L. delavayi*. This is clearly related to the fact that these two *Loranthus* species are dioecious as compared with synoecious for the other species. Because these two species occur on different clades (molecular and morphology trees), this character simply adds homoplasy and was thus not included.

**Char. 19. Style length**. This character has three states, long, medium and short. Only the outgroup *Cecarria* has long styles. Clades Lambertianus (medium) and Europaeus (short) are then differentiated by this character. Within Europaeus, *L. europaeus* has the longest style, possibly associated with its subdioecious sexual condition.

**Char. 20. Fruit length.** Smaller fruits are seen in the Odoratus clade as compared with larger fruits in the Europaeus clade plus *L. lambertianus*.

**Char. 21. Fruit width.** The same reconstruction on the tree as Char. 23 (fruit length) occurs with fruit width.