

# The Vegetation of Sulawesi

## II. Fine filter analysis

performed as part of the  
Ecoregional Conservation Assessment

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and  
Texas Tech University

A report prepared by Chuck Cannon

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## Existing Sulawesi botanical collections

The overall density of botanical collections on Sulawesi is one of the lowest of the major Indonesian islands with less than 25 collections per 100 km<sup>2</sup>. Collection effort has not been consistent on the island and a major gap exists in the record following World War II until the early 1970's, when collection boomed for a few years. Over the past decade, the rate of collection has not been maintained and appears to have suffered a substantial drop during the last few years of the 20<sup>th</sup> century and into the 21<sup>st</sup> (Fig. 1).

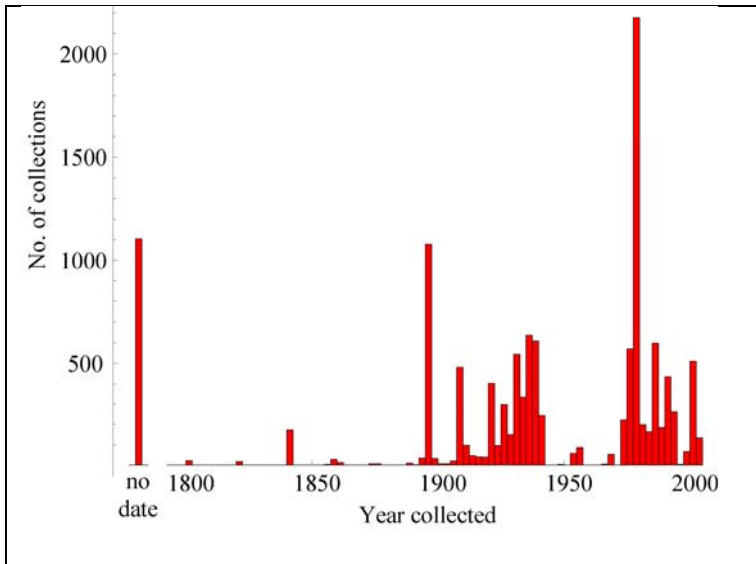


Figure 1. History of botanical specimen collection on Sulawesi. The first bar illustrates the number of collections without a recorded time of collection.

The current collection database contains over 15,000 records, of which 12,314 have been adequately georeferenced to allow spatial analysis. There are 2,148 unique species among these collections, including 946 genera from 170 families.

The most commonly collected species on the island is *Agathis celebica* Laubenfels (Araucariaceae) with 82 collections found in seven of the fifteen biogeographic sections and five of the sixteen forest classes, primarily in the

lowlands which is unusual for an *Agathis* species.

The most commonly collected genus is *Syzygium* (Myrtaceae) with 348 specimens, including only six described species. Fully 97% of these specimens remain unidentified at the species level, illustrating the level of taxonomic ignorance of the Sulawesi flora. This genus does represent a special challenge to SE Asian botanists as it remains poorly known throughout the region and a systematic treatment has never been written. On the other hand, the second most commonly collected group, the genus *Ficus* (Moraceae) or the figs, is one of the better known Southeast Asian plant groups and yet 22% of the 261 specimens collected remain unnamed at the species level. It is clear that one of the main limitations to any fine filter analysis of the Sulawesi flora is the fact that the vegetation is poorly collected and of these collections, relatively little taxonomic work has been completed, leaving many species unnamed and undescribed. Marco Roos and his co-authors have reported that only 45% of the 120 named families on the island have been formally treated in the Flora Malesiana series<sup>1</sup>.

<sup>1</sup> Roos, M. C., P. J. A. Kessler, S. R. Gradstein, and P. Baas. 2004. Species diversity and endemism of five major Malesian islands: diversity-area relationships. *Journal of Biogeography* 31:1893-1908.

## Herbarium collection density by biogeographic section

Diameter of circle indicates the number of  
georeferenced collections from each of the  
biogeographic sections recognized in this study.

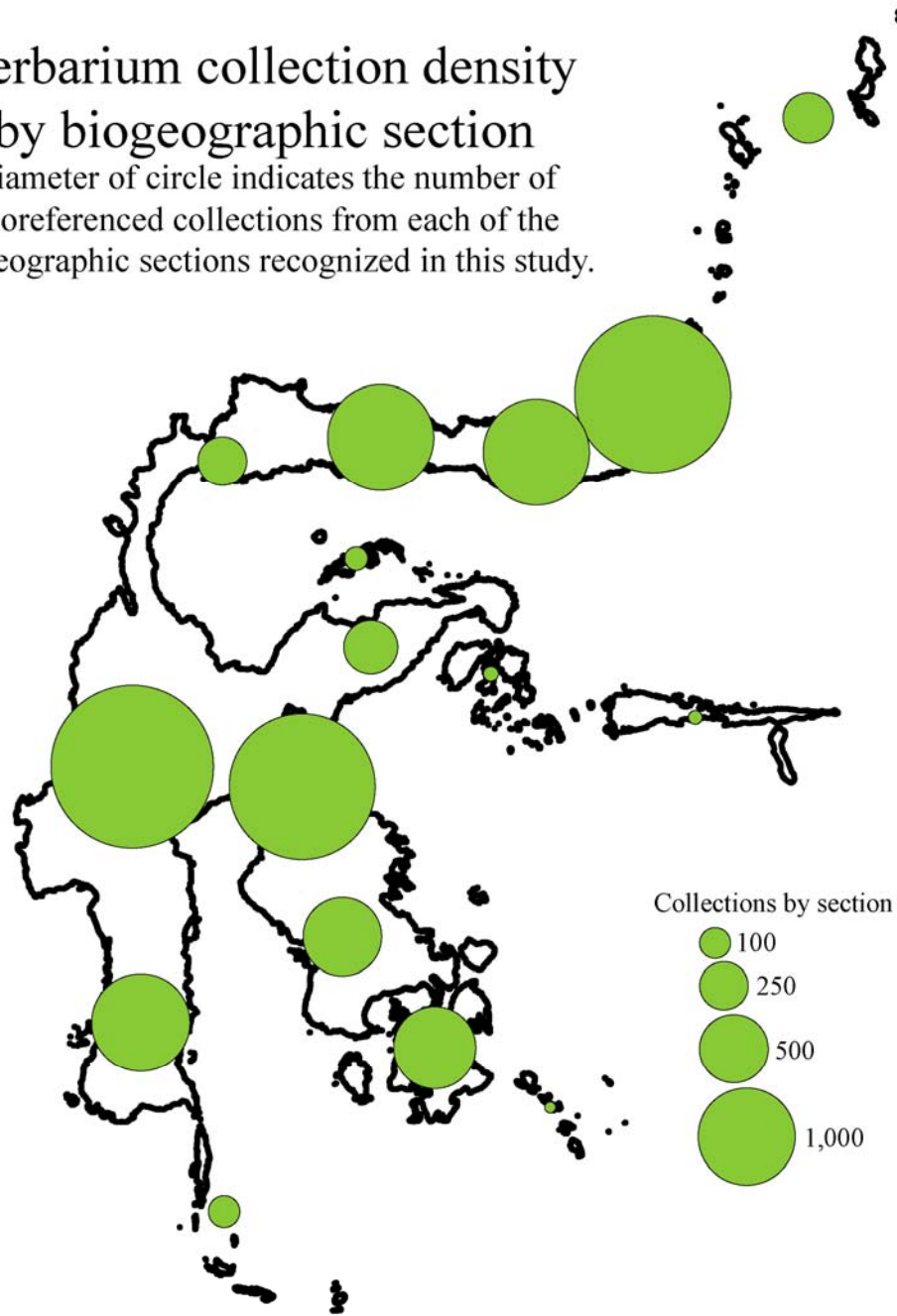


Figure 2. Collection density of botanical specimens by biogeographic section. The size of the circle represents the number of collections made in that region.

The botanical collection effort has historically been biased towards relatively few sites. In terms of the biogeographic sections identified in this Ecoregional Conservation Analysis, three sections clearly have much higher collection rates than the others (Fig. 2). Eastern North Sulawesi is by far the best collected region on Sulawesi, as over 2500 collections or 21% of the total database are from this region while it represents only 3% of total land area (Fig. 3). Eastern Central Sulawesi is also over-represented in the collection database with 18% of the collections (2259 specimens) from 11% of the total land area of the island. While Western Central Sulawesi is relatively well-collected with 23% of the specimens from 27% of the island's land area, these collections are tightly clustered in two areas (Fig. 4). Two biogeographic sections, Luwuk-Morowali and Western North Sulawesi, each represent roughly 9% of the land area, but less than 3% of the total collection effort (Fig. 3). South Eastern Sulawesi is relatively poorly-collected with only 5% of the botanical specimens from over 11% of the total land area.

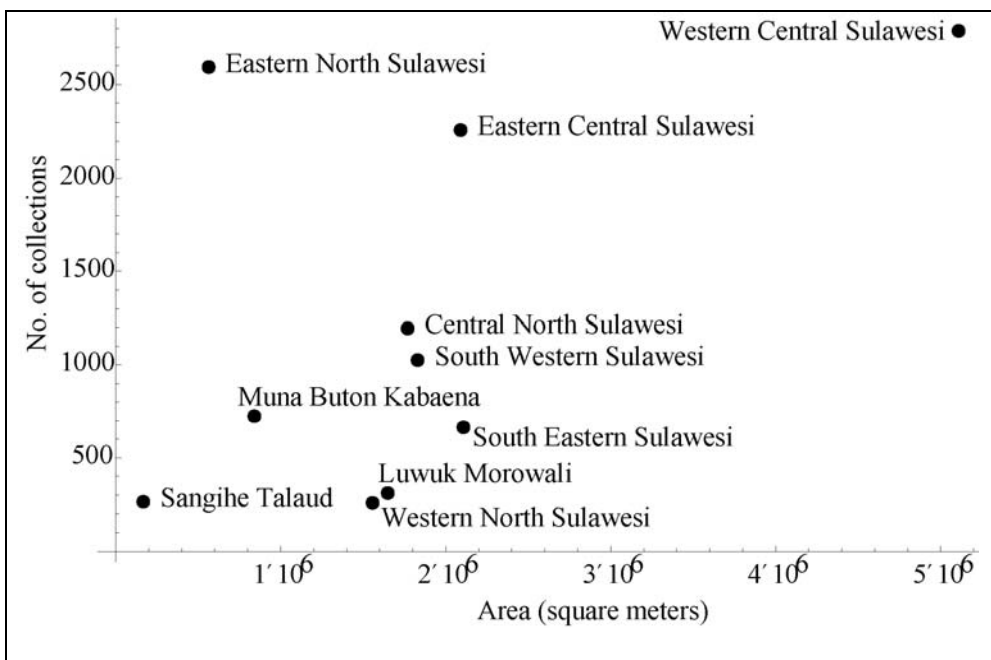


Figure 3. The relationship between the number of botanical collections available and the total land area of the major biogeographic sections on the island of Sulawesi.

Several of the smaller island groups are also poorly collected but are not shown in Figure 3 because of their relatively small geographic extent. For example, Sula island represents roughly 3% of total land area

in the ecoregion but less than 0.2% of the collections.

The geographic bias in the collection history is even more striking when the distribution of specimens is examined in terms of the kecamatan in which they were collected (Fig. 4). The vast majority of collections in Western Central Sulawesi come from only a few kecamatan, centered around the Lore Lindu National Park, while very few collections exist in the Lariang area to the west, which represents one of the largest lowland alluvial areas on the island and would also be the entry point for many species migrating from Borneo. The northern part of the Tana Toraja/Mamasa highland area, which contains most of the old-growth forest, is also very poorly known. This area contains several ancient rare plant species found nowhere else on the island (e.g.

# Herbarium collection density by kecamatan

Diameter of circle indicates the number of georeferenced collections from each administrative district at the kecamatan level.

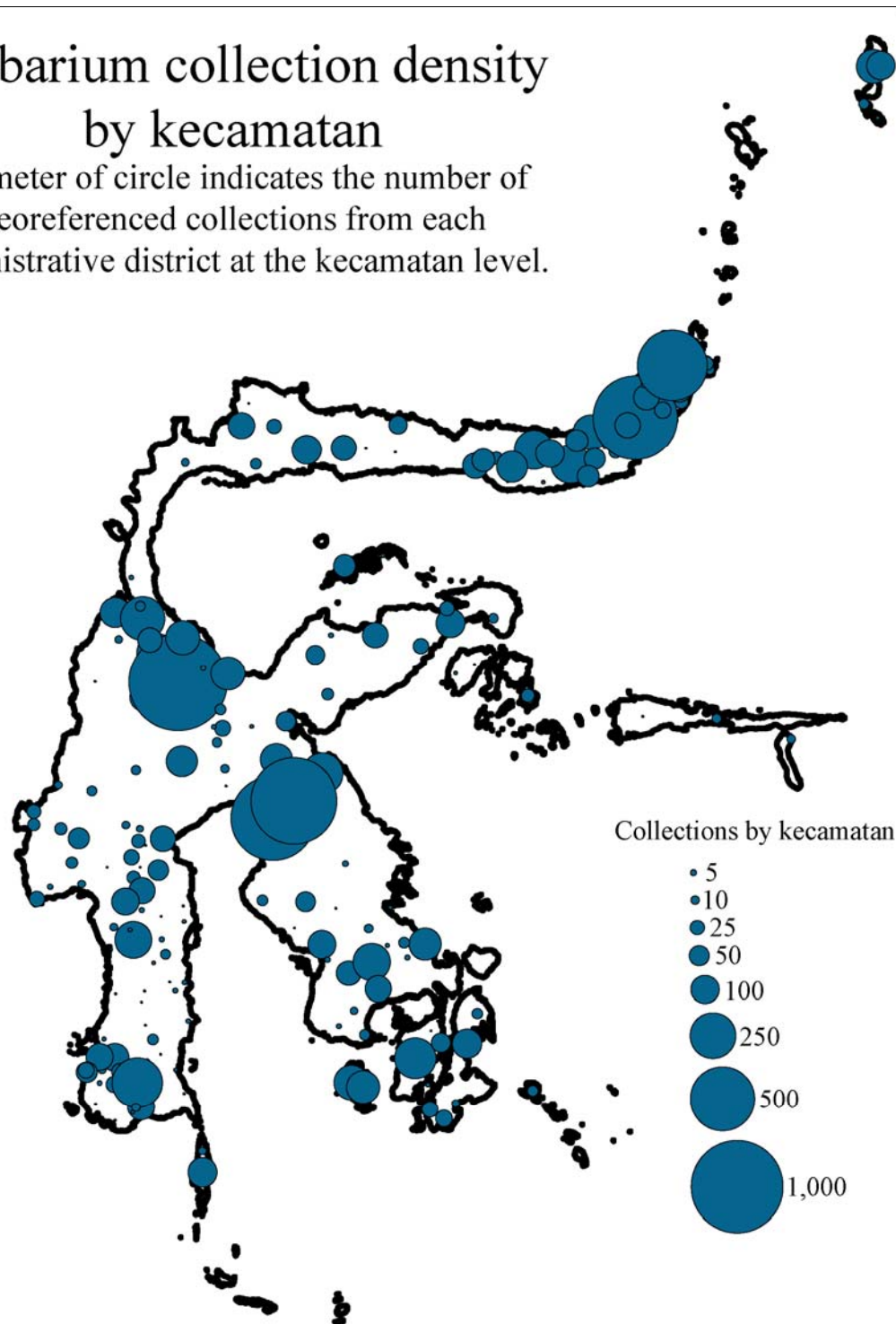


Figure 4. Collection density of botanical specimens by kecamatan on the island of Sulawesi. The diameter of the circle indicates the number of collections made within each administrative district.

*Trigonobalanus verticellata* Forman) and is probably somewhat of an ‘ark’ carrying species from Borneo from the former closer connection between the two islands.

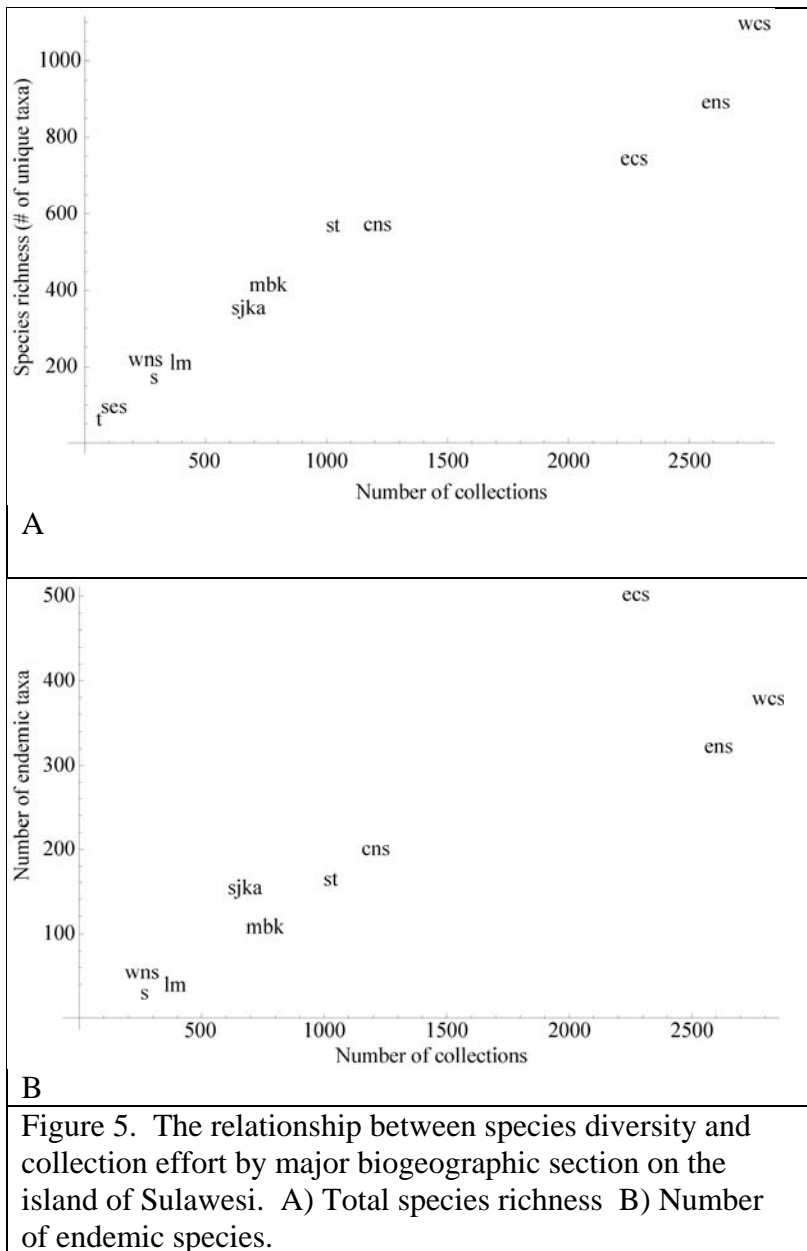
The pattern that the biggest patches of old-growth on the island are also some of the least collected continues in the southeast (Fig. 4), where one of the most interesting areas on the island has been collected very few times. This region, in the headwaters of the rivers flowing to the southeast, primarily through Kendari, contains a rich juxtaposition of a wide range of soils and forest types and possesses a large amount of G2G forest.

### Collection effort and rate of return

The number of unique species identified amongst a certain number of herbarium collections can be used as an estimate of the ‘species area curve’ (Fig. 5). The relationship between total species richness and the collection effort in a major biogeographic section is pretty consistent (Fig. 5A), with the only deviation being a slight lower rate of return in Eastern Central Sulawesi and Eastern North Sulawesi. Western North Sulawesi appears to have a higher rate of return but there are so few collections from this area that it is hard to judge whether this is simply an artifact of a small sample size or an actual indicator of additional richness in the region.

The pattern is less consistent when only the endemic species are considered. The collection effort in Eastern Central Sulawesi obviously produced a much larger number of endemic species

than both Eastern North and Western Central Sulawesi, given roughly equal numbers of



specimens (Fig. 5B). The variation among the other regions is also notable, with the Selayar island group apparently containing an unusually rich number of endemics. The greater richness of endemic species in the eastern part of the island makes sense because of both mafic and limestone soils are known to produce strong specialist species and to harbor odd plant groups.

When interpreting these results, the fact that many different potential biases in collection effort by region could be affecting these patterns. For example, the greater concentration of collectors on a few collecting sites in one region could reduce its relative overall diversity when compared to another region, where collecting efforts are spread over a larger and more varied area. These possible biases have not been carefully examined yet but given the almost linear pattern in overall species richness, any biases are probably not very strong.

### Association tests

The association between a particular plant species and either a forest class or biogeographic section was examined using a simple Monte Carlo technique. The approach compares the observed pattern against a large number of random patterns, generated from the data. For example, the most commonly collected species on the island (*Agathis celebica*) has 82 georeferenced collections. These collections come from five different forest classes and fifteen separate localities. To test the association with forest class, a random set of 82 forest classes are chosen out of the collection database. The number of times the actual observed forest classes are present is compared to the random sample and how many times that forest class is present. This is done hundreds of times to produce a distribution for each forest class. If the number of observed occurrences of a forest class lies outside the range of random occurrences of a forest class, given a particular number of collections, the association between the species and that forest class is considered significant. This approach is commonly used when the underlying distribution of the observations cannot be directly approximated by a normal distribution or parametric statistical approaches. This approach also imposes any undetected or unknown biases present in the data onto the statistical test. These tests were only performed on taxa with complete species names (excluding all of the indeterminate specimens) and only on named species with at least five specimens in the collection database. The collection database included 599 named species with more than 5 specimens in the database. The results are presented only for the 81 species for which a significant result was obtained in forest class associations and the 115 species with significant results from the biogeographic section analysis.

## Species associations with forest class

Strong differences are apparent in the patterns of species associations with the various forest classes. These differences are probably determined by several things but the most prominent factors would probably be the competitive status of each species in that forest class. Both the Lowland\_alluvium and Lowland\_intermediate classes had more negative associations than positive associations. This result is probably due to the fact that many specialist species, shown by the large number of positive species associations with forests in the upper elevations and on mafic soils, are not found in these lowland habitats and the large number of samples generally collected in the lowlands makes all of these absences significant. The only other forest classes with multiple negative associations are both upper elevation intermediate soils, again probably more an artifact of the greater number of collections available in these classes than in the actual 'avoidance' of these areas by species. The absence of the specialist species on these soil types can also be attributed to their competitive exclusion from the sites with richer soils because of the generally accepted trade-off between specializing on a limiting resource

**Table 1. Number of herbarium collections, species, ratio of species to collections, and significant species associations with each class among the 81 species with significant results.**

| Forest class         | No. of coll. | No. of spp. | Spp/coll | Positive | Negative |
|----------------------|--------------|-------------|----------|----------|----------|
| Lowland_alluvium     | 2046         | 892         | 0.44     | 17       | 19       |
| Lowland_intermediate | 5049         | 1529        | 0.30     | 8        | 54       |
| Lowland_limestone    | 654          | 402         | 0.61     | 5        | 1        |
| Lowland_mafic        | 1461         | 592         | 0.41     | 21       | 6        |
| Upland_intermediate  | 1086         | 604         | 0.56     | 16       | 2        |
| Upland_limestone     | 151          | 75          | 0.50     | 6        | 0        |
| Upland_mafic         | 68           | 53          | 0.78     | 5        | 0        |
| Montane_intermediate | 756          | 380         | 0.50     | 19       | 2        |
| Montane_limestone    | 3            | 3           | 1        | 0        | 0        |
| Montane_mafic        | 33           | 23          | 0.70     | 2        | 0        |
| Tropicalpine         | 467          | 230         | 0.49     | 14       | 0        |
| Karst_limestone      | 98           | 83          | 0.85     | 6        | 0        |
| Mangrove             | 24           | 18          | 0.75     | 1        | 0        |
| Wetlands             | 260          | 203         | 0.78     | 12       | 0        |

and maximizing the use of resources.

The lowland limestone forest class still has a very high species discovery rate, with 402 species identified within the 654 collections made. Only the upland intermediate class has a species discovery rate higher than 1 species for every two collections. The species discovery rate in the other well-collected forests (>500 collections) are all mostly greater than 1 new species in every three collections. This rate is still quite high. Many of the poorly collected forest classes would yield very high discovery rates, particularly the limestone areas which have the highest observed ratio of species to collections.

The association of *Agathis celebica* with the Lowland alluvium indicates that this Red-Listed species is certainly in danger of extinction, because of the relatively small amount of this forest class remaining undisturbed on the island. This status should

probably also be applied to *Beilschmedia gigantocarpa*, a good candidate for the IUCN list. One species, *Kjellbergiodendron celebicum*, is commonly considered a specialist on mafic soils, although in this analysis, it is positively associated with Lowland alluvium and actually negatively associated with Lowland mafic forests. The more widespread *Eucalyptus deglupta*, which is commonly found along river margins throughout the island, is also associated with this forest class but probably is not in as high a conservation concern. The other species associated with this forest class (*Hopea celebica*, *Gomphandra mappioides*, *Phytocrene macrophylla*, *Acalypha amentacea*, and *Aleurites moluccana*) are both associated with other forest classes as well. The *Hopea* species is particularly unusual because it is also associated with Upland limestone and Kart forests. This important representative of the Dipterocarpaceae family on the island should certainly be on the IUCN Red List.

An additional five species were associated with the Lowland intermediate forest class, all of them from different families, including a magnolia (*Elmerrillia tsiampacca*). Given the limited amount of good forest remaining in this class, these species should receive a higher level of protection and conservation status. A single species (*Lunasia amara*) was positively associated with Wetland forests.

**Table 2. The 25 most common species with significant associations with a particular forest class. Positive associations indicate that the species was found at a greater frequency than expected in that habitat, Negative associations is the opposite. The first capitalized letter indicates forest type (L=lowland, etc.), the lower case letter indicates geology (i = intermediate, etc.).**

| #  | Fam   | Species   | Positive      | Negative           |
|----|-------|---|---------------|--------------------|
| 82 | arauc | <i>Agathis celebica</i>                                   | La            | Li, Ll, Lm, Mi, Ui |
| 62 | balsa | <i>Impatiens platypetala</i><br><i>Kjellbergiodendron</i> | K, Mi, Mm, Ui | Li                 |
| 46 | myrta | <i>celebicum</i>  | La            | Mi, Ui             |
| 42 | sabia | <i>Meliosma sumatrana</i>                                 | Li, Mi        | La, Lm             |
| 36 | compo | <i>Vernonia arborea</i>                                   | Mi, Ui, W     | La                 |
| 34 | cucur | <i>Momordica cochinchinensis</i>                          | Li            | La, Lm             |
| 33 | winte | <i>Drimys piperita</i>                                    | Mi, T, Ui, Um | La, Li, Lm         |
| 31 | dipte | <i>Hopea celebica</i>                                     | K, La, Ul     | Li                 |
| 31 | ulmac | <i>Gironniera subaequalis</i>                             | La, Lm        | Li                 |
| 27 | icaci | <i>Gomphandra mappioides</i>                              | La, Lm, W     | Li                 |
| 25 | rosac | <i>Prunus grisea</i>                                      | La, Lm, W     | Li                 |
| 22 | laura | <i>Litsea timoriana</i>                                   | Li            | La                 |
| 22 | vitac | <i>Leea aculeata</i>                                      | Li            | La, Lm             |
| 21 | icaci | <i>Phytocrene macrophylla</i>                             | La, Ui        | Li                 |
| 21 | legum | <i>Serianthes minahassae</i>                              | La            | Li                 |
| 21 | rutac | <i>Lunasia amara</i>                                      | W             | La                 |
| 20 | lecyt | <i>Barringtonia acutangula</i>                            | K, Li         | La                 |
| 19 | myrta | <i>Leptospermum javanicum</i>                             | Mi, T, Um     | La                 |
| 18 | magno | <i>Elmerrillia tsiampacca</i>                             | Li            | La, Lm             |
| 17 | icaci | <i>Iodes cirrhosa</i>                                     | Li            | La                 |
| 16 | myrta | <i>Eucalyptus deglupta</i><br><i>Xanthostemon</i>         | La            | Li                 |
| 16 | myrta | <i>confertiflorum</i>                                     | Ul, Um        | Li                 |
| 15 | eupho | <i>Acalypha amentacea</i>                                 | La, Ui, W     | Li                 |
| 15 | myrsi | <i>Ardisia forbesii</i>                                   | Mi, T, Ua     | La, Li             |

Less common taxa not listed on the above table which are also associated with a single forest class are potentially endangered as well, although that depends on the status of the forest class and its general condition and conservation status. Two species are associated with Lowland mafic forests (*Carallia brachata* and *Gluta renghas*) and could potentially be endangered on the island. The second species is relatively common throughout Malesiana and is therefore probably not endangered, although its association with mafic soils may indicate a local specialization of a more widespread species. Two species are also associated with the Tropolpine forests (*Chionanthus laxiflorus* and *Adinandra masambensis*) but because of the relatively good condition of these forests, their conservation status should be considered relatively stable. Interestingly enough, the other *Chionanthus* sp. (*C. sulawesicus*) is associated with the Montane intermediate forests. This genus may be particularly good at specializing on various habitats. A ginger, *Etlingeria rosea*, is associated with wetland habitat.

#### Species associations with biogeographic section

A significant positive result of the association tests by biogeographic section should indicate those species which are locally restricted or endemic to each biogeographic section. These results provide a broader and more biologically reasonable test than simple endemism, as it allows a restricted species to be observed in a different region without completely losing its significance. The Eastern Central Sulawesi region contains a very large number of both positive and negative associations. In this case, the large number of specialist species found on the mafic and limestone soils in this region excludes the more common and widely distributed species found on intermediate soils. The high average elevation of Western Central Sulawesi probably also explains the large the high number of positive and negative species associations detected in this analysis. Eastern North Sulawesi has the greatest number of negative associations but relatively

**Table 3. Number of collections, number of species, ratio of discovered species to collections, and the significant associations with each biogeographic section among the 115 species with significant results.**

| <b>Biogeographic section</b> | <b>No. of coll.</b> | <b>No. of spp.</b> | <b>Spp/coll</b> | <b>Positive</b> | <b>Negative</b> |
|------------------------------|---------------------|--------------------|-----------------|-----------------|-----------------|
| Eastern North Sulawesi       | 2594                | 884                | 0.34            | 14              | 56              |
| Central North Sulawesi       | 1195                | 563                | 0.47            | 19              | 5               |
| Western North Sulawesi       | 258                 | 191                | 0.74            | 7               | 0               |
| Western Central Sulawesi     | 2788                | 1087               | 0.39            | 24              | 22              |
| Luwuk Morowali               | 311                 | 198                | 0.64            | 6               | 0               |
| Eastern Central Sulawesi     | 2259                | 737                | 0.33            | 38              | 31              |
| South Eastern Sulawesi       | 664                 | 345                | 0.52            | 19              | 1               |
| South Western Sulawesi       | 1026                | 561                | 0.55            | 16              | 9               |
| Muna Buton Kabaena           | 724                 | 406                | 0.56            | 14              | 4               |
| Sula                         | 22                  | 20                 | 0.90            | 1               | 0               |
| Banggai Peleng               | 24                  | 20                 | 0.83            | 2               | 0               |
| Sangihe Talaud               | 264                 | 183                | 0.69            | 3               | 0               |
| Selayar Jampea Kayu Adi      | 110                 | 86                 | 0.78            | 8               | 0               |
| Togian                       | 61                  | 53                 | 0.87            | 5               | 0               |
| Paternoster Kalotoa Tukang   | 14                  | 12                 | 0.86            | 3               | 0               |

few positive associations. This pattern is probably due to the relative geographic isolation of the eastern end of the northern arm, which should greatly restrict the immigration of any plant species which cannot cross large bodies of open water.

South Eastern Sulawesi contained a relatively high number of positive species associations with only one negative association. The lack of negative associations in this region, dominated by limestone and mafic soils, may simply be due to the much smaller sample size because the same patterns for Eastern Central Sulawesi should be apparent. The Muna\_Buton\_Kabaena island group leads the smaller islands for positive species associations by a wide margin (a much larger collection has also been made from these islands). All of the other island groups did not have any negative associations, once again, probably largely due to small sample sizes. The Sangihe\_Talaud islands are particularly low in positive associations, given that 264 collections have been made there, especially when compared to the Selayar and Togian groups, which both have more positive associations based upon substantially smaller collection sizes (110 and 61, respectively).

**Table 4. The 25 most common species with significant associations with a particular biogeographic section, indicating a localized distribution on the island. Positive associations indicate that the species was found at a greater frequency than expected in that habitat, Negative associations is the opposite.**

| #  | Fam   | Species  | Positive              | Negative                |
|----|-------|--|-----------------------|-------------------------|
| 82 | arauc | <i>Agathis celebica</i>                                    | BP, ECS, SWS          | CNS, ENS, MBK, SES, WCS |
| 62 | balsa | <i>Impatiens platypetala</i>                               | WCS                   | ENS                     |
| 59 | arauc | <i>Agathis dammara</i>                                     | ECS, SES, WCS         | ENS, MBK, SWS           |
| 56 | myrta | <i>Metrosideros petiolata</i><br><i>Kjellbergiodendron</i> | CNS, ECS, SES         | ENS, MBK, SWS, WCS      |
| 46 | myrta | <i>celebicum</i>   | ECS                   | SWS, WCS                |
| 42 | sabia | <i>Meliosma sumatrana</i>                                  | ENS, WCS              | ECS, MBK, SWS           |
| 38 | apocy | <i>Alstonia spectabilis</i>                                | ECS, SJKA, T          | CNS, ENS                |
| 34 | cucur | <i>Momordica cochinchinensis</i>                           | CNS, WCS              | ECS, SWS                |
| 33 | myris | <i>Myristica fatua</i>                                     | CNS                   | ECS, SWS                |
| 33 | winte | <i>Drimys piperita</i>                                     | LM, SWS, WCS          | ECS, ENS                |
| 32 | myris | <i>Myristica simiarum</i>                                  | BP, CNS, ENS          | ECS, SWS                |
| 31 | dipte | <i>Hopea celebica</i>                                      | ECS                   | CNS, ENS, WCS           |
| 31 | eupho | <i>Alchornea rugosa</i>                                    | LM, MBK, PKTB, SES, T | ECS, WCS                |
| 31 | myris | <i>Knema cinerea</i>                                       | CNS                   | ECS, ENS                |
| 31 | ulmac | <i>Gironniera subaequalis</i>                              | ECS                   | CNS, ENS, SWS           |
| 29 | cappa | <i>Capparis pubiflora</i>                                  | WCS                   | CNS, ECS, MBK           |
| 27 | eupho | <i>Macaranga tanarius</i>                                  | MBK, T                | ENS                     |
| 27 | sterc | <i>Kleinhovia hospita</i>                                  | LM, SWS               | ECS                     |
| 25 | thyme | <i>Phaleria capitata</i>                                   | CNS                   | ECS, WCS                |
| 24 | melia | <i>Dysoxylum nutans</i>                                    | WCS, WNS              | ECS, ENS                |
| 24 | morac | <i>Artocarpus fretissii</i>                                | ENS                   | WCS                     |
| 24 | sapin | <i>Allophylus cobbe</i>                                    | CNS, PKTB, ST, WCS    | ECS, ENS                |

The plight of *Agathis celebica*, discussed above in the forest class-species association section, becomes even sharper with a close look at its geographic distribution on the island, with two positive associations (Banggai islands and South Western Sulawesi) areas which have undergone a great deal of conversion and disturbance. No species was solely associated with the South Western Sulawesi biogeographic section, which is probably a fortunate thing. The two species commonly associated with mafic or poor soils (*Kjellbergiodendron celebicum* and *Metrosideros petiolata*) are concentrated in Eastern Central and South Eastern Sulawesi, where mafic soils are most common. The second species has a wider distribution, also being found in Eastern Northern Sulawesi. This may be an example of an expanded habitat range and recent invasion of the northern arm across the bay.

Two species (*Impatiens platypetala* and *Capparis pubiflora*) were solely associated with Western Central Sulawesi. Both of these species are members of herbaceous groups and a probably a product of the generally higher elevation in this region. Two more species (*Chionanthus laxiflorus* and *C. sulawesicus*, not among the top 25) were also associated with this section and a single forest class (Tropalpine and Montane intermediate, respectively). These species are both geographically and ecologically restricted in their distribution, further raising their conservation status: neither of these species is on the IUCN Red List. The other three are all small trees or shrubs, most likely associated with the higher elevations found in this biogeographic section. Only one species (*Dysoxylum nutans*) is associated, either positively or negatively, with Western North Sulawesi. This section has a low collection rate and its biogeographic position as the isthmus connecting the greater part of the northern arm to the central part of the island probably reduces the number of species which would be endemic there. The very large mountain on this isthmus certainly warrants exploration.

### Specific plant groups

The results from detailed analyses of several narrowly defined plant groups are shown in Appendix 1. These plant groups include 1) local endemics, 2) positive association, 3) negative association, 4) orchid, and 5) IUCN Red List species. The analysis of these groups was performed from the perspective of biogeographic region. Those species in bold-faced text are included on at least two different lists within each biogeographic region and are therefore of extra conservation concern.

### **Local endemics**

For the purposes of this report, 'local endemic' plant species were identified simply by their presence in a single biogeographic section, irregardless of forest class. The vast majority of these species were collected a single time. While this might indicate the presence of an extremely rare and ecologically vulnerable population of plants, our basic understanding of the biology of extreme rarity among plant species is weak. There are many other possible explanations for the taxonomic description of a new taxon from only a few or even a single specimen besides the existence of a viable population of

reproductively isolated individuals, collectively known as a 'species'. Three probable explanations for the existence of these phenotypic variants are

1. the interaction of two more common species in a hybrid zone, stable or not, and the production of divergent morphologies, which may or may not be evolutionarily successful.
2. Some studies have shown, among temperate plants, that taxonomically described species are actually diseased or mutant individuals of well-known and more common species.
3. The plant species is difficult to collect or notice and therefore rarely collected. A species which has only been collected a single time is, by default, 'endemic', no matter what its true distribution. This fact usually indicates a poor sample more than any biological reality. In the author's personal experience, 'endemic' species have often merely been overlooked elsewhere.

At this point, it seems unwise to place much conservation value on these extremely rare taxa, because of the poor general collection record and our current understanding of the evolutionary and ecological significance of these taxa.

Well over half (1227 out of 2148 or 58%) of all named species in the Leiden collection database are 'locally endemic' to a biogeographic section on the island. Out of these species, 902 taxa are known from only a single collection and 186 from two collections. This indicates that 88% of these locally endemic species are possibly artifacts of a limited sample. Because this analysis only includes plant species with a taxonomically recognized name, i.e. a specific epithet is provided, not merely 'sp.', the numbers are slightly different than those shown in Figure 5B. The results in this section are more conservative and possibly, although unlikely, an underestimate of the levels of local endemism. None of the biogeographic sections appear to contain unusually high or low numbers of locally endemic species.

In the Eastern North section, fourteen species were collected five times or more but none of these species produced a significant result in the association tests (see Appendix 1 – 'Eastern North' worksheet). This discrepancy probably indicates that the association test, as implemented here, is a bit too stringent and as the overall number of collections increase for an area, the number of false negatives increases. These local endemics are almost all found in the Lowland Intermediate or Lowland Alluvium forest classes and were collected in areas which now tend to be in open or poor condition. For this analysis, an additional ten species were collected four times in this section and no where else. All 24 of these locally endemic species should be considered vulnerable. Four species on the IUCN Red List are endemic to the Eastern North section. Three of these species are in the same family and genus (Meliaceae: *Aglaia*), which can be important hornbill or primate fruits, while the last species is in the kayu malam genus of *Diospyros*, a timber for which Sulawesi was once famous.

In the Western North section, the locally endemic *Baccaurea papuana* was collected four times, possibly indicating that these species may be restricted in its distribution. In the Western Central section, which is the best collected section on the island, twenty species were collected four times or more. Only three of these species

were found in the lowlands while ten were collected in the tropalpine forests. All of them were on intermediate soils and the vast majority was collected in a location that remains in good to old-growth condition.

The Eastern Central section contained ten locally endemic species which were also positively significant in the association tests and another ten species were represented by between four and six collections. The majority of these species (14) were found in Lowland Mafic forest class. Seven were collected in the Lowland Alluvium class, most of the collection localities are in fair to open condition. A few of these species do appear to be pioneers: *Glochidion lutescens*, *Mussaendopsis celebica*, *Macaranga celebica*, and *Tetractomia barringtonioides*. This list also includes one rare species of the Dipterocarpaceae family: *Vatica flavovirens*. The South Eastern section contains probably the most interesting species of the Dipterocarpaceae on the island, *Hopea gregaria*, which has been collected seven times only in this section. This species should certainly be listed as critically endangered and vulnerable as it is found in the highly disturbed Lowland Intermediate forest class.

The South Western section only included five species which were locally endemic and were collected four or more times. Two of these were orchids (*Habenaria rumphii* and *Robiquetia bicurris*) and one was from the Australasian plant family Proteaceae (*Helicia teysmanniana*). Only *Salacia ledermannii* on the smaller islands of Muna, Buton and Kabaena could be considered locally endemic to any of the smaller island satellite groups.

### Orchids

The orchid family was represented in the database by 276 specimens collected in 65 different localities, including eleven different biogeographic sections and thirteen different forest classes. These specimens included 148 different taxa from 55 different genera, indicating a very high level of diversity for these collections. Over 80% of these species have been collected less than three times, which makes detailed study of their distribution impossible. One of the problems is that orchid specimens do not make good dried herbarium specimens, because the vast majority of the taxonomy depends upon the details of floral morphology. Dried orchid flowers retain little of their taxonomic information. This group requires expert knowledge to be studied adequately. Given the constant variety encountered in the field and the tiny populations supporting these 'species', it is probably better to save the forest by looking at the trees. We will not soon see the end of morphological diversity in orchids.

Among the biogeographic sections, the Western North region appears to contain an unusually large number of orchid species, with 16 unique taxa among only 258 total collections. This density of orchid collections is much higher than the Central North region where 15 orchid species have been recognized among 1195 collections. The Eastern Central section appears a bit lower than would be expected, given the number of orchid collections elsewhere, with only 22 species recognized among 2259 species. The Western Central section contained the most species (50).

Only five species in two biogeographic sections are sufficiently collected to be considered 'locally endemic': *Dendrochilum edentulum*, *Dendrochilum macrobulbon*, and *Epiblastus masarangicus* in the Western Central section and *Habenaria rumphii*

and *Robiquetia bicruris* in the South Eastern section. Very few of the other orchid species have been collected more than a single time. While the orchids are one of the few 'charismatic' plants, our extremely poor understanding of their biology and distribution and the trivial amount of ecosystem services and biomass they contribute to any landscape certainly diminishes their conservation value and importance from a management standpoint.

### Figs

The fig family was represented in the database by 409 specimens collected in 103 different localities, including twelve different biogeographic sections and twelve different forest classes. These specimens included eleven different genera. The figs dominated these specimens, with 261 specimens named to the *Ficus* genus, while *Artocarpus* was the second most dominant (61 specimens). The fig specimens included 41 unique species, of which 20 species are known only from two specimens or less. The ecological importance of the figs to animal communities in the tropical forests of Southeast Asia cannot be understated. These plants provide valuable keystone food resources to a wide variety of vertebrates and insects. Many of the species regenerate quite well after major disturbance of the canopy and a high density of tall strangler figs in an area is actually a pretty good indicator of a major disturbance in the not so distant past. The canopy trees left standing after such a disturbance become overgrown with strangler figs in the new high light environment surrounding them. The figs then may also play a key role in the recovery of an area after disturbance, as they maintain and possibly expand a closed canopy and attract frugivores and seed dispersers who may 're-seed' these forests. This canopy closure is critical for the re-establishment of old growth species.

Thirteen species of fig were included in the association tests but none of them were significantly associated with either a biogeographic section or a forest class, despite the fact that more than eight of these species were represented by ten specimens in the collection. The three most common species were *Ficus variegata*, *Ficus septica*, and *Ficus ampelos*. This lack of significant association, despite their abundance in the database, could be hampered by the relative difficulty in proper identification of dried fig specimens. Almost a quarter of the specimens remain unnamed at the species level. Another factor is the 'universality' of the general fig habitat, the larger species of which become established as epiphytic seedlings and the remainder are generally pioneer species.

This lack of geographic specificity continued to be true among the 'locally endemic' species, with only a single species (*Ficus copiosa* in Eastern North Sulawesi) was collected at least four times and found only in a single biogeographic section. These series of results seem to indicate that figs could largely be dealt with as a single class of plants, probably best distinguished by growth form, and that the details of species composition can largely be ignored.

## IUCN Listed Species

Unfortunately, the only officially listed plant species incorporated into this analysis are the taxonomic names drawn from the IUCN Red List. Out of the 83 species on the IUCN Red List, twenty-nine of these are not part of the Leiden collection database. Eastern Central Sulawesi possessed the greatest number of listed plants, with 33 total species, while Western Central and Eastern North had 23 and 22 species respectively. Eastern Central also contained the most positively associated (6) and locally endemic (8) species and three of these species (*Kalappia celebica*, *Knema matanensis* and *Myristica ultrabasica*) were both positively associated and locally endemic. Four of the species in the Eastern North were locally endemic while none of the listed species in Western Central were positively associated or locally endemic. South Western Sulawesi also had two positively associated and one locally endemic species, making it the only other biogeographic section with more than one list species which was also restricted in its distribution.

Currently, our ability to identify and target plant species which are endangered and require special conservation status is poor. The results from this fine filter analysis should be incorporated back into the IUCN Red List, as there are numerous species which are not listed which obviously do need special status. Additionally, a fairly large proportion of the plant species listed for the island are not even present in the collection database, which brings into question the veracity of the list in general. A few of the species listed should not be given special status, most notably a taxon like *Octomeles sumatrana*, which has a widespread distribution in SE Asia and can readily be found in disturbed forests on most of the major islands.

## General species results

| <u>Most common species</u> |        |                                     | <u>Most common genera</u> |        |                    |
|----------------------------|--------|-------------------------------------|---------------------------|--------|--------------------|
| # coll                     | Family | Species                             | No. coll                  | Family | Genus              |
| 82                         | Arauc  | <i>Agathis celebica</i>             | 348                       | Myrta  | <i>Syzygium</i>    |
| 62                         | Balsim | <i>Impatiens platypetala</i>        | 261                       | Mora   | <i>Ficus</i>       |
| 59                         | Arauc  | <i>Agathis dammara</i>              | 179                       | Laura  | <i>Litsea</i>      |
| 56                         | Myrta  | <i>Metrosideros petiolata</i>       | 174                       | Saurau | <i>Saurauia</i>    |
| 47                         | Eupho  | <i>Mallotus mollissimus</i>         | 153                       | Clusi  | <i>Garcinia</i>    |
| 46                         | Myrta  | <i>Kjellbergiodendron celebicum</i> | 147                       | Arauc  | <i>Agathis</i>     |
| 42                         | Sabia  | <i>Meliosma sumatrana</i>           | 131                       | Melia  | <i>Aglaia</i>      |
| 41                         | Anaca  | <i>Koordersiodendron pinnatum</i>   | 124                       | Elaeo  | <i>Elaeocarpus</i> |
| 40                         | Flaco  | <i>Homalanthus populneus</i>        | 124                       | Eupho  | <i>Glochidion</i>  |
| 39                         | Eupho  | <i>Macaranga hispida</i>            | 123                       | Eupho  | <i>Macaranga</i>   |
| 38                         | Apocy  | <i>Alstonia spectabilis</i>         | 120                       | Eupho  | <i>Mallotus</i>    |
| 37                         | Magno  | <i>Elmerrillia ovalis</i>           | 114                       | Rubia  | <i>Psychotria</i>  |
| 36                         | Compo  | <i>Vernonia arborea</i>             | 112                       | Ebena  | <i>Diospyros</i>   |
| 35                         | Anaca  | <i>Buchanania arborescens</i>       | 105                       | Myrist | <i>Myristica</i>   |
| 35                         | Anaca  | <i>Dracontomelon dao</i>            | 101                       | Burser | <i>Canarium</i>    |
| 35                         | Faga   | <i>Lithocarpus celebicus</i>        |                           |        |                    |
| 34                         | Cucur  | <i>Momordica cochinchinensis</i>    |                           |        |                    |
| 33                         | Winter | <i>Drimys piperita</i>              |                           |        |                    |
| 33                         | Myrist | <i>Myristica fatua</i>              |                           |        |                    |
| 32                         | Myrist | <i>Myristica simiarum</i>           |                           |        |                    |
| 31                         | Dipte  | <i>Hopea celebica</i>               |                           |        |                    |
| 31                         | Myrist | <i>Knema cinerea</i>                |                           |        |                    |
| 31                         | Sapot  | <i>Palaquium obtusifolium</i>       |                           |        |                    |
| 31                         | Sapin  | <i>Pometia pinnata</i>              |                           |        |                    |

The most common fifteen genera in the collection database were from 13 different families. These common genera are well-represented throughout Southeast Asia and do not present a unique set of diversity at this taxonomic

level. Almost all of them are important fruit species for vertebrates. These genera include familiar and economically important plants like ebony (*Diospyros*), nutmeg, (*Myristica*), dammar (*Agathis*), and figs (*Ficus*). A number of genera are common pioneer taxa, e.g. all three genera of the Euphorbiaceae.

Two *Agathis* species are in the top three most commonly collected species from Sulawesi, which is a bit surprising because these are large trees producing rather bulky cones, particularly the seed cones. The Anacardiaceae family is well represented in this collection, particularly the economically valuable timber species *Koordersiodendron pinnatum*.

### Summary

The flora of Sulawesi is quite poorly known in its detailed taxonomic composition and the biogeographic distribution of these taxa. Many plant groups remained undescribed and untreated, particularly among those plants found on Sulawesi. This limitation hampers our ability to understand both the number of species endemic to the island and to any one biogeographic region. Most botanists who have worked either on the island or with a substantial collection of herbarium specimens report that numerous undescribed species remain to be discovered. In the Kew Bulletin, ten new species of

*Elaeocarpus* were described by M.J.E. Coode in a single publication and he insists that further study would produce an even greater number, particularly in the upper elevation areas. The highly biased geographic distribution of the existing collections also limits the overall interpretation of the collection database. Compared to the island of Borneo, the collection density is substantially lower while the geographic, geological, and climatic complexity is probably at least an order of magnitude higher. Greater landscape complexity is generally associated with higher diversity and local endemism. If Sulawesi does not have possess an unusually high number of species or endemics, this is at least partly due to our lack of knowledge.

The best strategy to remedy this situation would probably be carefully designed survey trips to several of the regions highlighted by the ECA as being of critical conservation value. These surveys, instead of attempting to be exhaustive in nature, should instead focus on several key plant groups, depending both on the results from this analysis and the availability of taxonomic expertise for those plant groups. These surveys should also serve to establish long term monitoring plots across a range of forest types and conditions. These surveys and plots should be centered around a short list of 'indicator species' - those species which are clearly associated with a particular habitat - in combination with 'species of high conservation value', such as important crops for frugivores or endemic to a particular biogeographic section.

These efforts, if they are going to be attempted, should be done **NOW**, so that a solid understanding of baseline 'natural' conditions can be developed for the purposes of monitoring future changes. Not only is Sulawesi a biodiversity hotspot but it is also probably a very good model system for examining global climate change. Most species on the island, simply because of its biogeographic complexity, have small population sizes and the immigration between appropriate and inappropriate habitat for specialist species, because of this spatial complexity, could be quite sensitive and vulnerable to any climate change, primarily in terms of rainfall patterns. Unlike Borneo and the other large islands, Sulawesi has never been connected to a continent and the sea level changes through the glacial periods had little effect on its land area, meaning that at least one aspect is controlled.