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Chapter 1

Vascular plants of the Kaijende Highlands, Papua New Guinea: Taxonomic and vegetation survey

Wayne Takeuchi

SUMMARY

The flora of the Kaijende Highlands is described from a rapid assessment survey of its principal montane habitats, with specific emphasis on three vegetation formations: 1) lower montane forest, 2) upper montane forest, and 3) subalpine grassland. Species-level determinations are provided for most of the 759 specimens obtained during the survey. The checklist of inventoried species includes 492 tracheophytic taxa (112 ferns and lycophytes, 6 gymnosperms, 69 monocots, and 305 dicots), from a total of 262 genera.

At least 16 plants are determined as species new to science, including five arborescent taxa, five understory shrubs, two vines, two orchids, and two ferns. Other botanical results are presented with commentary on their presumed significance. The collective findings are distilled into a conservation-focused discussion highlighting the taxonomic and ecosystem value of the most notable plants.

INTRODUCTION

The botanical survey in regional context

Although the true size of its inventory is unknown and subject to considerable speculation, there is no doubt that New Guinea is home to one of the world's richest floras. According to most modern estimates, approximately 15,000–20,000 species are probably present on the island (Davis et al. 1995). Using orchids and ferns as benchmarks for extrapolation, the most recent assessment places the upper limit at 25,000+ vascular plants (Supriatna 1999).

A remarkable feature of New Guinea's floristic diversity is that several groups attain levels of species richness usually seen only on continental spatial scales. Ferns, for example, are represented by an astonishing total of 3,000 species (Parris in press) and orchids by 2,800 species (Vogel and Schuiteman in press). This extraordinary diversity has arisen largely under the influence of one of the most active orogenies on earth. The Central Cordillera has the highest peaks in Malesia and the richest assortment of montane plant life in the Indo-Malayan region. With an estimated 5,000–6,000 species in 9,000 sq. km (Davis et al. 1995), the area centered on Mt. Wilhelm and its environs (including all of the Kaijende Highlands) comprises one of the world's five phyto-maxima for vascular plant diversity (Barthlott et al. 1996, 2005).

Despite Papua New Guinea's (PNG) floristic wealth, our knowledge of this resource is still substantially incomplete. Seven of the 10 species of *Homalium* are known only from single specimens (Craven 1979, Steenis 1982), and of the 50 species of Papuan *Marsdenia*, 32 are still known just from their type localities (Forster 1995). There are similar examples of sampling gaps in virtually every major plant family. The documentation deficiencies can be attributed in large part to the erratic spatial distribution of past collecting. Although the number of botanical surveys in PNG has increased substantially since 1950, many areas remain practically unknown (Frodin 1990).

The unevenness in exploration coverage is reflected in two geographic patterns on the horizontal and vertical dimensions: 1) collections density decreases from east to west, with Indonesian Papua (previously Irian Jaya) having received considerably less attention than PNG, and 2) documentation intensity increases markedly with elevation, such that montane environments are generally much better known than the lower elevation flora. However there is a manifest spottiness superimposed over these large-area patterns. Thus while the Highlands provinces have the best collective documentation of any administrative or biotic region in PNG, many individual districts on the cordillera are still poorly surveyed. Enga has the lowest sampling coverage of any province in PNG (as measured by representation in the New Guinea Force and Lae Herbarium number series) despite the high collections density for the Highlands as a whole (Takeuchi and Golman 2001). The unexpected number of taxonomic discoveries made during the Kaijende survey is primarily attributable to these spatial disparities in historical activity.

METHODS

The Kaijende Highlands botanical survey was centered on two field camps and along service roads near the Porgera Joint Venture (PJV) open-pit mine in Enga Province, PNG.

The first study site at Omyaka was an irregular mosaic of mossy forest and *Chionochloa-Arundinella-Deschampsia* grassland (camp at 05°31'37" S, 143°03'23" E, 3,200 m elevation). A second venue at Lake Tawa (camp at 05°35'43" S, 142°50'26" E, 2,117 m elevation) consisted primarily of colline communities arranged in bands around a closed valley. The Lake Tawa locality included an unusual series of catchment lakes draining into sinkholes at the southeastern head of the basin. Most areas examined during the survey are situated inside a potential conservation zone currently under consideration for Conservation Area designation.

Twelve days of intensive fieldwork were allocated to the bivouac localities: August 21–24 at Omyaka and August 26–September 2 at Lake Tawa. The remaining period from September 4–9 was devoted to walk-through inspection of habitats between Porgera Town and the Porgera Reservoir, using the PJV staff accommodations (Suyan Camp) as a logistical base.

The Kaijende study was organized on sampling procedures commonly employed in Conservation International (CI) biosurveys (Mack 1998, Mack and Alonso 2000, Beehler and Alonso 2001). As with previous operations, the botanical fieldwork was focused exclusively on tracheophytic plants (i.e. ferns, gymnosperms, and angiosperms). Herbarium specimens were taken from all fertile taxa encountered by three surveyors, using tree climbers and 15 m extensible pruning poles as required. Sterile specimens were not collected.

Accessory documentation in the form of bottled flowers, xylarium samples, and photographs (5-megapixel digital

imagery) were obtained from selected collections. Specimens for exsiccatae were secured in sets of 1–12 duplicates and field-packed in 70% ethanol for subsequent processing at Lae. Identifications were done primarily at the PNG Forest Research Institute (FRI) and Lae National Herbarium (LAE), using keys from formally published literature and/or by comparison to authoritatively annotated reference sheets. If several revisions are available for a particular genus or family, the most recent one was selected as a basis for the identifications.

The plant collections have been compiled in a checklist, with taxonomic comments and determination credits appended as appropriate. Genera were assigned to families in conformity (p. p. maj.) with the following sources: ferns and lycophytes (Holttum 1959, Croft 1986), gymnosperms (Laubenfels 1988), and angiosperms (Angiosperm Phylogeny Group 1998, 2003).

RESULTS

General description of the vegetation

The surveyed areas are classified by the Forest Inventory Mapping System (FIMS; the planning database of the PNG Forest Authority) primarily under vegetation codes **L** (small crowned lower montane forest), **Mo** (very small crowned montane forest), **Ga** (alpine grassland), and **Gi** (subalpine grassland), (see Hammermaster and Saunders (1995a) for a description of these units). The reader is also referred without further comment to map overlay SB 54-8, showing the spatial distribution of vegetation types throughout the Porgera-Koroba region (Hammermaster and Saunders 1995b).

Existing forest classification systems for PNG are constrained by the unwieldy mapping scales at which they are presented. Many communities encountered by the survey team are discretely repeating entities easily recognized on the ground, but are below the spatial resolution capability of the FIMS, a system generally available only in 1:250,000 scale. Even the limited-issue 1:100,000 agency maps are inadequate for tracking specialized communities (e.g. montane bogs, lacustrine habitats, limestone outcrops) which are typically small in size but of considerable conservation interest. Despite its limitations, there is no typing system in New Guinea more versatile than FIMS. The alternative schemes (Paijmans 1975, 1976; Johns 1977; Saunders 1993a, b) lack the digital and GIS (Geographic Information System) linkages afforded by the FIMS classification.

The most significant vegetation units seen during the survey are described below with specific reference to dominant or indicator species, irrespective of whether the communities are included on the FIMS. In cases where the community corresponds to a particular mapping category, the applicable codes are indicated in parentheses.

Upper montane forest (Mo). This formation (acronym UMF) generally occurs above 3,000 m, and is often described as 'mossy forest' or 'elfin woodland'. It includes forest types

traditionally regarded as 'subalpine'. Under the FIMS classification subalpine forests are not recognized as structurally distinct entities, and are lumped into an inclusive 'Mo' designation [see Grubb and Stevens (1985) for evidence against this procedure]. All of the genera considered diagnostic for the UMF (Hammermaster and Saunders 1995) are present at Omyaka. Subalpine forest (sensu Grubb and Stevens 1985) is also present in the proposed WMA as tracts of appreciable size, even though their existence is obscured by the FIMS methodology. A transition from UMF to *Nothofagus*-dominant and coniferous forest (codes LsN and Lc) occurs at lower elevations near the border with Southern Highlands Province (Hammermaster and Saunders 1995b), but the RAP reconnaissance did not enter those formations.

The Kaijende UMF is characterized by low (<10–14 m) trees with gnarly moss-enveloped stems and depauperate crowns. Microphyllous and nanophyllous taxa are dominant to such an extent that representatives from different families are very similar in vegetative aspect and difficult to distinguish except by close inspection. *Decaspermum alpinum*, *Eurya brassii*, *Ilex archboldiana*, *Prunus pullei*, *Quintinia kuborensis*, *Symplocos cochinchinensis* var. *orbicularis*, *Syzygium alatum*, *Vaccinium apiculatum*, and *Xanthomyrtus compacta* are the most common arborescent taxa (Photos 1–6). The tallest trees are represented mainly by gymnosperms, but the emergents are not conspicuous, being only slightly higher than the surrounding forest and consisting for the most part of widely scattered *Libocedrus papuana* var. *papuana*, *Podocarpus crassigemma*, *Phyllocladus hypophyllus*, and *Dacrydium imbricatus* var. *robustus*. *Drimys piperita* (as entities *coriacea*, *heteromera*, and *montis-wilhelmi*), is the most frequent undershrub (Photos 7–8).

Melicope brassii, *M. robbinsii*, *Olearia durifolia*, *O. platyphylla* var. *cinerea*, *O. spectabilis*, *Vaccinium amblyandrum*, *V. schoddei*, and *V. stricaule* var. *adenodes*, are conspicuous woody taxa on forest margins (Photos 9–10). The border vegetation often forms a structurally distinct scrub (code Sc) with the same signature genera as the UMF proper, but with reduced statures (<6 m) and higher population densities. At Omyaka the forest-scrub and grassland formations combine in a highly irregular mosaic composed of interpenetrating strips, fingers, and islands. This situation is beyond the mapping capability of the FIMS, and such areas are typically charted as composite entities (e.g. as 'Mo/Ga/Sc' at Omyaka Camp).

Many vining species of *Rubus*, including *R. archboldianus*, *R. lorentzianus*, *R. montis-wilhelmi*, and *R. royenii* var. *bispidus*, are present in the forest-grassland contact. The local populations of the *R. declivus-trigonus* complex are of particular taxonomic interest and significance. However with the exception of *Rubus* and *Dimorphanthera*, lianes were notable more for their overall absence or rarity than for any special occurrences. In contrast to other montane localities, the epiphytic flora was poorly developed but two new orchids have been determined from the collections (N. Howcroft pers. comm.).

Tussock grassland (Ga, Gi). Kaijende Highland environments include large expanses of tussock grassland which appear homogeneous in gross aspect, but which actually exhibit considerable differentiation in species composition and community structure. This spatial variation probably reflects differences in successional status and fire incidence. At Omyaka Camp (located several kilometers from the access road and thus presumably with reduced fire frequencies), the dominant grass is the large tussock-forming *Chionochloa archboldii* (Photo 11). *Arundinella furva* and *Deschampsia klossii* are smaller and relatively minor species interspersed through the *Chionochloa* clusters. In areas with more human traffic (e.g. Porgera Reservoir and the Reservoir access road), a shift in species composition is evident, and *Poa keysseri* ssp. *keysseri* becomes the dominant bunchgrass. The likelihood of greater fire influence at these latter sites is implied by higher frequencies of *Imperata conferta* (kunai), and *Eulalia leptostachys*, taxa which often indicate for disturbance.

Although the open areas are mapped by FIMS exclusively as Ga- and Gi-coded grassland, several floristically discrete associations were discerned within those formations. There are for example, sizable areas of heath-like shrubbery scattered through the grass and consisting of *Hypericum macgregorii*, *H. papuanum*, *Coprosma papuensis* ssp. *discolor*, *Drapetes ericoides*, *Rhododendron commonae*, and *Styphelia suaveolens*. At Omyaka (e.g. 05°31'31" S, 143°03'13" E) the *Hypericum* association can encompass areas of a hectare or more, often dominating the inter-ridge clearings (Photos 12–15). On a more local basis, the continuity of the grassland is also broken by large ferny patches of *Blechnum revolutum*, *Plagiogyria egenolfioides* var. *decrescens*, *Gleichenia erecta*, and *G. vulcanica*. Of particular interest are the extensive savanna-like sections where tree ferns assume visual and stature prominence. *Cyathea dicksonioides* and *C. atrox* var. *inermis* are co-dominants within this association. Other species (*C. lepidoclada*, *C. aff. magna*) are also occasionally present as volunteers or possibly as relicts from a retreating UMF margin.

The non-grass associations intergrade with the grassland sens. str. in such a way that sharp divisions cannot be drawn on the ground. But they are still taxonomically and structurally recognizable as separate units. For conservation purposes, the FIMS procedure of lumping all open areas into a common grassland classification is too inexact. Several communities of exceptional composition and interest are hidden by such a procedure.

Montane bogs (Ga, Gi, Sc, in part). Bogs of the Kaijende Highlands are comprised of two principal facies: one dominated by *Sphagnum*, and the other by hemispherical hummocks or cushions of *Astelia alpina*, *Danthonia oreoboloides*, and *Oreobolus*. The *Sphagnum* facies is found in hollows and flats where the water table is suspended on the surface. Hummock bogs are apparently not under topographic control and can form even on knolls and moderate slopes. Both types occur in grassland mapped by FIMS as 'Ga' and 'Gi', or in conjunction with low scrub (Sc). Indi-

vidually and collectively the bogs are of very limited size and thus particularly susceptible to disturbance and alteration. Because of their small areas, they are invisible to all existing systems of vegetation classification in spite of their distinctive appearance.

As with other plant associations in the Kaijende grasslands, the bogs intergrade with surrounding vegetation. However they have a common core of diminutive character taxa including *Drosera peltata* ssp. *peltata*, *Eurya brassii* ssp. *apiculata*, *Gentiana ettingshauseni*, *Ischnea elachoglossa*, *Keysseria radicans*, *Myriactis cabreriae*, *Potentilla foersteriana*, *P. papuana*, *Ranunculus wahgiensis*, *Scirpus crassiusculus*, *S. mucronatus* ssp. *clemensiae*, *S. subtilissimus*, *Vaccinium amblyandrum*, and *V. stellae-montis* (Photos 16–21).

The Kaijende bogs are approximately assignable to the short grass bog, *Astelia* subalpine bog, and hard cushion bog of earlier investigators (Wade and McVean 1969, Hope 1976b). In view of the considerable variation exhibited by Papuanian mires, it is hardly surprising that the Porgera examples differ in many respects from the associations discerned elsewhere. *Sphagnum* bogs for example are not regarded as comprising a discrete facies on New Guinea summits, although they are clearly present in the Foja Mts. of Indonesian Papua (pers. obs.) as well as in the Kaijende Highlands.

In addition to the *Sphagnum* and hummock bogs with their characteristic physiognomy, there are numerous areas of similarly poor drainage scattered through the grassland. These swampy sections often have slow-moving water flowing along well-defined channels. An edible watercress (*Rorippa nasturtium-aquaticum*), usually forms a dense groundcover in such situations. Drainage lines in *Cyathea* savanna are clearly visible even over considerable distances because of color contrasts between the *Rorippa* and adjacent vegetation.

Lower montane forest (L). The lower montane forest (acronym LMF) was seen only around the closed valley at Lake Tawa. Canopy statures in this formation are much higher than in the UMF (to ca. 30 m at Lake Tawa) and collections were correspondingly harder to obtain. Unlike the subalpine zone, where most of the woody taxa have probably been enumerated, the greater part of the LMF flora undoubtedly remains unrecorded. Of the 23 character genera for the LMF (fide Hammermaster and Saunders 1995a), only eight were checklisted at Lake Tawa.

The forest types at Lake Tawa are arranged in elevationally sequenced bands around the valley floor (Photos 22–23). This is clearly shown by the FIMS, and was also verified by ground reconnaissance. Of particular interest are the limestone outcrops (05°35'54" S, 142°50'07" E) where three new species were discovered. Unfortunately the *Nothofagus* forest to the southwest of the camp could not be reached because of rugged terrain.

Syzygium (particularly *S. effusum*), *Symplocos cochinchinensis* ssp. *leptophylla* (vars. *leptophylla* and *monticola*), and *Lithocarpus rufovillosus* were apparently the most frequent

canopy trees in the Lake Tawa LMF, but impressionistic evaluations of this sort are not always reliable. An observer's attention is understandably directed at fertile taxa, and such plants will tend to receive excessive weight in post-survey reporting. Under different phenological circumstances, rapid assessment estimates could change substantially. Unlike the high-elevation formations at Omyaka, the Lake Tawa stands were predominantly sterile during the survey's visit and the identities of many overstory species were not determinable.

Irrespective of the unfavorable canopy conditions, *Cyathea atropinosa* and *C. magna* were clearly the most exceptional understory plants in terms of frequency and visual apparency. The ground layer was generally species-poor and mostly represented by urticates.

Near the floor of Tawa valley, the LMF has a well defined border with emergent stands of 20 m+ *Pandanus* (section *Intraobtus*). On its downslope side the forest border opens abruptly into a herbaceous mat association surrounding the catchment basin lakes (Photo 24). The lakefront zone is comprised primarily of *Cardamine keysseri*, *Hydrocotyle sibthorpioides*, *Hypericum* cf. *papuanum*, *Isachne pauciflora*, *I. villosa*, *Oenanthe javanica*, *Oxalis corniculata* var. *sericea*, *Polygonum longisetum*, *P. strigosum*, and *Viola arcuata*, and is under water during periods of high rainfall (Photos 25–27). In foothills to the north and west, multistoried LMF forest is replaced by pandan savanna-scrub with a *Dicranopteris-Gleichenia*-Ericaceae groundlayer (Photos 28–29). *Pandanus* crowns of this latter vegetation are often festooned by pendulous sprays of *Asplenium nutans* and *Belvisia validinervis* var. *longissima*. *Vaccinium auriculifolium* and *Glochidion* sp. nov. (aff. *dumicola-oogynum*) are the most common savanna shrubs.

Noteworthy collections

The expedition checklist currently consists of 492 vascular plant taxa (Appendix 2). Included in the collective accounting are 112 pteridophytes (ferns and lycophytes), 6 gymnosperms, 69 monocots, and 305 dicots. The tallies are distributed through 25 pteridophyte families, 3 gymnosperm families, 87 Angiosperm Phylogeny Group families, and a cumulative total of 262 genera.

No claim is made regarding the comprehensiveness of the Kaijende checklist. Rapid assessment procedures are incapable of achieving sampling saturation and will usually reveal only the most salient qualities of an investigated flora. However the large number of montane taxa represented by multiple gatherings is a circumstantial indication that a substantive coverage of the macroflora has probably been secured.

Porgera is a locality of major economic importance to PNG (the open-pit mine accounts for 14% of the country's export earnings and was the world's eighth largest gold producer in terms of 2005 output), so it is reasonable to assume *a priori* that botanical collections have already been taken from the general vicinity. Despite this expectation, examination of LAE institutional logbooks shows no evidence of

earlier work in the district. From the number of significant findings made by the survey, it can be inferred that floristic exploration either has not occurred within the proposed conservation tract, or was superficial in scope.

Distributional records, rare taxa of conservation value, species new to science, and other noteworthy plants, are briefly presented in the following narrative. Author citations are specified in the text when a binomial is not on the checklist. Numbers refer to the survey vouchers. First sets and holotypes are at LAE; second sets at Arnold Arboretum. Residual duplicates have been distributed to appropriate specialists at other institutions.

Actinidiaceae

Saurauia sp. nov., ser. *Setosae*; Lake Tawa: 20066; Paiela Road: 20087; Waile Creek: 20310. Photos 30–31.

There are three collections of a distinctive microphyllous species with conspicuously serrate leaves. The erect inflorescence is seemingly uniflorous, but on some branches the flowers are dichasial, so the new plant is probably best placed in *Setosae* rather than *Uniflorae* (but see comments in Smith 1941: 502). *Saurauia altiterra*, *S. giluwensis*, and *S. trugul* are frequent associates.

Identifications in this genus are particularly problematic. The last comprehensive treatment (Diels 1922) has become acutely outdated by events over the past 85 years. Royen (1982) reviews only the alpine taxa.

Although the various species of *Saurauia* are among the most characteristic plants of montane environments, few botanists are willing to attempt determinations in this speciose and unrevised genus. At Lae Herbarium the unnamed collections are nearly 3x the number of identified sheets (975/344 by manual count), a proportion which is probably similar to the holdings in other herbaria. Many identifications are of dubious accuracy.

Araliaceae

Polyscias belensis Philipson; Lake Tawa: 19771.

Polyscias belensis was known to Philipson (1978, 1979) from a small number of specimens obtained in Irian Jaya (Lake Habbema) and from Morobe Province (Wau-Aseki) in PNG. A recent collection from the Bismarck Range represented the first report of this species from the PNG Highlands (Takeuchi 1999a). Judging from material present at Lae Herbarium, there are no contemporary records other than the Bismarck gathering.

Polyscias belensis and *P. ledermannii* (Photo 32) can be found in mixed populations and are easily confused when occurring together. Although rarely reported by botanists, the many sightings from Lake Tawa suggest that *P. belensis* may be more common than previously suspected.

Athyriaceae

Diplazium sp. ?nov.; Lake Tawa: 19952.

The survey specimen appears to represent a new taxon distinguished by large cordate scales on the pinnae bases.

Elaeocarpaceae

Aceratium ledermannii Schltr.; Lake Tawa: 19949.

The species of the *ledermannii-oppositifolium* complex are lowland plants with documented occurrences to 300 m elevation (Coode 1981: 43). The survey collection from 2,300 m represents a substantial extension in vertical range.

Ericaceae

Dimorphanthera sp. nov.; Omyaka Camp: 19571; Waile Creek: 20206. Photo 33.

Dimorphanthera sens. lat. was recently revised by Stevens (2004). The expedition numbers are closest to *D. ingens* (Sleumer) Stevens on the latest treatment, but differ in the fascicled inflorescence, and by the indument on pedicels and the corolla tube.

Diplycosia sp. nov.; Paiela Road: 20000.

The new species is similar to *D. lamii* J.J. Sm., but has considerably smaller flowers (corolla to 3 mm long).

Vaccinium stellae-montis Sleumer; Omyaka Camp: 19699.

Formerly regarded as endemic to the Star Mts. The Omyaka specimens are from miniature plants in *Sphagnum-Oreobolus* bogs.

Euphorbiaceae

Breynia collaris Airy Shaw; Lake Tawa: 19996.

Breynia collaris is a high elevation shrub known from four collections originating in the Eastern Highlands (Airy Shaw 1980). LAE has only one genuinely annotated specimen (Brass 30440; cited in the protologue). The survey record extends the species range slightly to the west and into Enga Province.

Glochidion sp. nov., aff. '*dumicola-oogynum*' facies; Lake Tawa: 19806, 19994, 20025.

The new species has the smallest leaves and fruits of any Papuan congener, and capsules strongly resembling those of *Phyllanthus*. The similarity to *Phyllanthus* is so pronounced that the plant was repeatedly misidentified in the field. However the connate stamens, absence of disk glands, and the styles united into a cylindrical column, are more characteristic of *Glochidion*.

Macaranga sp. nov.; Lake Tawa: 19931, 19938. Photo 34.

The large single stipules and long-peduncled inflorescence indicate a clear relationship to Whitmore's '*longistipulata* group' (Whitmore 1980). Among the members in that complex, the new species is closest to *M. papuana* (J.J. Sm.) Pax and Hoffm., but is immediately distinguished by the thickly coriaceous leaves and entire fruits (leaves thin-textured and fruits furnished with flexible processes in *M. papuana*).

Lomariopsidaceae

Elaphoglossum angustifrons Holtt.; Lake Tawa: 19842.

At the time of the last generic treatment (Holttum 1978) *E. angustifrons* was known only from the type specimen, obtained 12 miles north of Minj in Western Highlands Province. Shortly after the Holttum revision, the fern was also found in the Mt. Hagen area by Parris and Croxall (coll. nos. 8176, 8177, 9388). The latest collection from Lake Tawa is the third known locality for the species and the first record for Enga Province.

Monimiaceae

Palmeria clemensae Philipson; Lake Tawa: 19981. Photo 35.

Palmeria clemensae is a widely distributed but infrequently collected species (Philipson 1982: 98). There are no prior reports of this vining plant from Enga Province or from the former Western Highlands District to which Enga had been administratively attached until 1975.

The survey specimen is an example of Philipson's 'western form', distinguished by leaves with bristly hairs concentrated along the veins.

Myrsinaceae

Rapanea (= *Myrsine*) sp. nov.; Waile Creek: 20275.

The new species has an unusual combination of red corollas, consistently pentamerous flowers, and a lepidote indument on vegetative parts. On Royen's (1982) treatment the survey collection falls between *R. borgmannii* Royen and *R. communis* Royen (= *R. cacuminum* and *R. leucantha* respectively, fide Sleumer). Using Sleumer's (1986) key, all credible leads end in impasse and the affinity is uncertain.

Myrtaceae

Syzygium sp. nov., aff. *goniocalyx* (Laut.) Merr. & Perry; Lake Tawa: 19873, 19987B. Photo 36.

The deeply channeled calyx tube is very distinctive and suggestive of *Syzygium goniocalyx*. However the vegetative characteristics are inconsistent with that species. In the most recent revision for Papuasias, Hartley and Perry (1973) provided a provisional key to a conspectus of 138 species. Many hundreds of unidentified collections have been made in the ca. 30 years since their preliminary review. At least 20 undescribed species are probably present in these newer gatherings.

Syzygium sp. nov., aff. *malaccense* (L.) Merr. & Perry; Lake Tawa: 20018.

The flowers of the presumed novelty have the characteristic appearance of *S. malaccense* sens. lat., but the small suborbicular leaves are far outside the range of variation even for that polymorphic complex.

Oleaceae

Jasminum sp. nov.; Omyaka Camp: 19581, 19596; Waile Creek: 20298. Photos 37–38.

The new species differs from the related *J. domatiigerum* in the small glabrous leaves without domatia, conspicuously glandular-punctate undersurface, and the terminal congested inflorescence. Several LAE collections of this taxon have been annotated by R. Kiew as *J. domatiigerum* var. nov. Royen (1982) had noted the existence of foliar variation in *J. domatiigerum* and uncharacteristically adopted an excessively wide interpretation of that species. However the variation is not random. In contrast to collections referred to *J. domatiigerum*, the Kaijende populations are found only as long-branching shrubs in the tree fern savanna or its margins, and never as forest climbers.

Orchidaceae

Glossorhyncha spp. nov.; Lake Tawa: 20035; Waile Creek: 20241 ex Beehler (dets. by N. Howcroft).

Two collections of *Glossorhyncha* have been determined as undescribed species and are presently under study for future publication by N. Howcroft (pers. comm.).

Polyosmaceae

Polyosma sp. nov., aff. *occulta* Reeder; Paiela Road: 20148.

The undescribed *Polyosma* with foliaceous bracts is nearest to *P. occulta*, but differs significantly from that species in the following respects (corresponding character states for *P. occulta* in parentheses): vegetative parts glabrous (velutinous or puberulent); lamina oblanceolate, 1.5–2.5 cm long (elliptic or oblong-elliptic, 3.5–5.0 cm long); racemes 1.0–1.5 cm long, axes glabrous (3–6 cm long, rachis subvillous); bracts unlobed and glabrous (tri-lobed and subsericeous); flowers 2–8 (8–20); calyx 2.5 mm long, (4.5 mm long), tube 0.9–1.0 mm by 0.7 mm (2 mm by 1.5 mm); corolla 0.8 mm diam. (2 mm diam.). Reeder (1946) gives an informative discussion of the *occulta* facies and related species.

Polypodiaceae

Selliguea costulata (Ces.) Wagner & Grether; Lake Tawa: 19877 ex Beehler.

The survey collection from 2,300 m represents a substantial extension in elevational range. *Selliguea costulata* had been previously recorded from sea level to 1,600 m (Hovenkamp 1998a: 43, 1998b: 198). At higher elevations this species merges with *S. lauterbachii* (Brause) Hovenkamp, and the two ferns can be difficult to separate (ibid.). The continuous nature of the variation is exemplified by another survey collection (20017A, from the same locality as 19877) in which the diagnostic features for each taxon are intermixed.

Ranunculaceae

Ranunculus uncostigma Merr. & Perry, or aff.; Paiela Road: 20104, 20190; Waile Creek: 20293.

The species was previously known from two collections obtained in Indonesian Papua (Irian Jaya) during the Archbold Expedition of 1938–9 (Merrill and Perry 1943, Royen 1982). *Ranunculus* is a common genus in high montane habitats, but many botanists apparently ignore these plants, judging from the fact that most of the existing material has been acquired by relatively few collectors. Notwithstanding their small size, *Ranunculus* species are not difficult to find and are easy to collect.

The identification of many taxa is complicated by variability in indument, leaf form, and staminal number. Royen's (1982) key is frequently unworkable because supposedly diagnostic character states often fall between the couplets or apply in part to either fork. Nearly every botanical author comments on the desirability for more collecting within their specific areas of interest, to a point where such advisories are almost banal. However the need for serial collections is especially obvious in this genus.

Rosaceae

Rubus sp., aff. '*diclinus-trigonus*' facies; Paiela Road: 20093A; Waile Creek: 20225. Photos 39–40.

The survey collections have the leaf characteristics of *R. diclinus* and the flower dimensions of *R. trigonus*. Kalkman (1987) noted the close relationship between these species but accepted their separation because of presumed distinctions in leaflet and flower size. Possible hybridization is indicated by the intermixing of characters in Kaijende populations, although *R. diclinus* and *R. trigonus* are not represented in the survey collections. The presence of an intergrading series also suggests that the *diclinus-trigonus* facies comprises a single continuum of variation, and may be undeserving of recognition as separate taxa.

Rubiaceae

Psychotria sphaerothyrsa Val.; Lake Tawa: 19940.

This species was previously recorded from West Sepik Province (two collections; Sohmer 1988) and Central Province (one collection; Merrill and Perry 1946). In more recent years, *P. sphaerothyrsa* has been found in the lowland forests of Crater Mountain (Takeuchi 1999b). The survey specimen was obtained at a substantially higher elevation (2,340 m) than the 1,000 m limit previously supposed for *P. sphaerothyrsa*. The new locality record also exhibits several aberrant qualities relative to the species sens. str. (the usual character states of *P. sphaerothyrsa* are given in parentheses) viz., the conspicuously hairy leaves (entire plant glabrous), 13–18 secondary veins per side (22–28 pairs), pyrenes 7–8 mm long (3–4 mm long), and branchlets emyrmecophilous (branchlets ant-inhabited). In other respects, particularly the unusual double-inframarginal vein, the Lake Tawa specimen shows good agreement with *P. sphaerothyrsa*. Although the nonconforming features may be sufficient to justify

recognition of a new taxon, the differences are also reasonably attributable to elevation-related variation. The Kaijende plants are thus provisionally regarded as an extreme form in an ecocline series whose elements will eventually be connected by future collecting. Sohmer (1988) was uncertain of the fruit color. The ripe pyrenes at Lake Tawa were red.

Rutaceae

Acronychia emarginata Laut.; Lake Tawa: 20017B.

An occurrence record from Enga Province is added to the poor documentation for *A. emarginata*, known with certainty from six prior collections. The Lake Tawa specimen was from limestone.

Acronychia foveata Hartley; Lake Tawa: 20065.

Acronychia foveata is an infrequently collected endemic, previously recorded only from Morobe and Southern Highlands Province. The four known collections are historical specimens from LAE's early institutional series (NGF 21201!, 37080!, 37090!, 39820!).

Acronychia richards-beehlerii Takeuchi 2007; Paiela Road: 20119. Photo 41.

The new plant is distinguished from all Papuan congeners by the combination of trifoliolate leaves and deeply fissured ovary and fruits. The epicarp is conspicuously rugose in the manner of *A. foveata* and *A. smithii* Hartley, but the former species has unifoliolate leaves and the latter has unfissured ovaries and fruits. On Hartley's (1974a, b) treatment the Kaijende specimen is superficially similar to the Australian endemics *A. suberosa* C.T. White and *A. choorechillum* (F.M. Bailey) C.T. White.

Solanaceae

Solanum nolense Symon; Lake Tawa: 19904.

Solanum nolense was previously known only from the type collection, a fruiting specimen obtained in 1977 between Mendi and Nol. Symon's (1985) protologue explicitly notes that the upper parts of the plant are unarmed. The Kaijende material is amply aculeate over the entire length of the stem axis, including the uppermost sections. The partially inermous character of the type is thus coincidental, and not germane to the species. Unlike most Papuan congeners, the petals are white. A complete specimen with fruits and anthetic flowers was found at Lake Tawa.

Thelypteridaceae

Mesophlebion sp. nov.; Waile Creek: 20272.

A peculiar species, exactly matching Pullen 5117, annotated by Holtum as *Mesoneuron spinuliferum* sp. nov., but apparently a nomen nudum requiring formal description.

Pneumatopteris sp. nov., aff. *caudata* (Holt.) Holtt.; Lake Tawa: 19947.

The new species was found on limestone exposures above Lake Tawa. It is closest to *P. caudata* but differs in the creep-

ing rhizome, smaller pinnae, and the glabrous indusia and veins.

Pneumatopteris petrophila (Copel.) Holtt.; Lake Tawa: 19953.

Except for the Papuan type, *P. petrophila* is known primarily from a few localities in northeastern PNG (Holttum 1973, 1981). The survey specimen was obtained on a limestone outcrop with *Pneumatopteris* sp. nov.

Urticaceae

Pilea sp. nov., aff. *zaranensis* Royen; Paiela Road: 20144; Waile Creek: 20277, 20283. Photo 42.

The three collections are unlike any urticate sheet at LAE, although the species is very common on forest margins and in *Cyathea* savanna. The new taxon's identifying features are the extensively branched and sprawling habit, strigulose indument, and small leaves (to only 1.5 cm long) with conspicuously toothed margins. On adaxial surfaces the lamina is distinctively marked by black discoid glands.

DISCUSSION

Comparisons with other surveys

On a per diem basis, the expedition's 759 collections are among the highest sampling results achieved by CI-RAP assessment in PNG. Compared to other surveys of equivalent duration, the 491-morphospecies checklist is also one of the better enumerations produced by recent investigations.

Upper montane vegetation is typically species depauperate in relation to lower elevation habitats, so reduced taxonomic counts are expected even with good collections coverage. The Kaijende sampling productivity is mainly attributable to reduction of canopy stature at the UMF study sites and a resulting increase in the accessibility of collection targets. Exemplary service infrastructure, and logistical support of a quality rarely experienced by field teams, also contributed significantly to the advantages afforded by in situ conditions.

Even without these factors it is generally much easier to develop checklists of montane plants in comparison to lowland ones because of the favorable phenologies to be found at higher elevations. Most plants in the UMF have substantially longer flowering periods relative to the LMF flora (Grubb and Stevens 1985). Surveyors on a limited schedule are thus more likely to find fertile individuals in upland habitats like Omyaka, and will nearly always get poorer results from sites like Lake Tawa. Similar elevational patterns have been consistently experienced by RAP botanists on Papuan surveys (e.g. Takeuchi and Wiakabu 2001). In UMF-subalpine environments at least some individuals of a given species will be found in fertile condition, while the same is not true when working in lowland areas.

The taxonomic results at Porgera can be compared with a recent survey in the Karius Range (April 24–May 9, 2005, at localities 40 km SSW and 52 km SSE of Lake Tawa; see Takeuchi 2005). The Karius survey used the same proce-

dures applied at Porgera; with three botanical surveyors on a 16-day field itinerary, but was focused on lower elevations (bivouacs at 1,370 m and 2,270 m). The Karius tallies are listed below with the corresponding Kaijende figures in parentheses:

From a total of 568 (759) collections, the Karius census recorded 401 (492) vascular plant taxa, consisting of 89 (112) ferns and lycophytes, 3 (6) gymnosperms, 21 (69) monocots, and 288 (305) dicots. The registers were distributed through 23 (25) pteridophyte families, 3 (3) gymnosperm families, 84 (87) Angiosperm Phylogeny Group families, and a cumulative total of 250 (262) genera. It should be noted that while the values are similar in most categories, the Karius numbers were based on substantially fewer collections, and half of the time was spent on limestone karst. The comparative figures primarily reflect 1) an increase in diversity of herbaceous plants at higher elevations, and 2) the greater efficiency of floristic surveys conducted in upper montane environments. An expected reduction of generic-level diversity in UMF habitats [see review of montane floristic patterns in Grubb and Stevens (1985) and Pajmans (1976)] is not apparent in the cross-tabulations. The superior collections coverage achieved at Kaijende conceals some of the taxonomic patterns that should ordinarily have emerged in the comparison with lower elevation environments. Checklists from Doma Peaks (Gillison 1970, Kalkman and Vink 1970), Fatima Basin-Mt. Kerigomna (Grubb and Stevens 1985), Mt. Jaya (Hope 1976b), Mt. Trikora (Mangen 1993), and Mt. Wilhelm (Hoogland 1958, Wade and McVean 1969, Johns and Stevens 1971) provide floristic summaries of other upper montane localities.

Ecological and biogeographic status of the Kaijende flora

Enga Province is one of the most rugged physiographic districts in Papuaia, as seen by the fact that its 12,800 sq. km territory includes a higher proportion of upper montane (>3,000 m) environments than any other province in eastern New Guinea (Löffler 1977). Because of the prevalence of high elevation habitats, areas like Kaijende are characterized by pronounced dominance of microtherm families, most notably by Cunoniaceae, Epacridaceae, Ericaceae, Geraniaceae, Myrsinaceae, Podocarpaceae, Ranunculaceae, Rosaceae, Theaceae, Violaceae, and Winteraceae. These temperate-latitude elements are represented by genera with geographic affinities to the northern hemisphere (e.g. *Ranunculus*, *Rhododendron*, *Vaccinium*, *Viola*) or by a distinct Antarctic component of southern origins [e.g. *Astelia*, *Coprosma*, *Dacrydium*, *Drimys*, *Gaultheria*, *Gunnera*, *Olearia*, *Podocarpus*, *Rapanea*, *Rubus*, *Styphelia*, *Trochocarpa*, and *Xanthomyrtus*; see Good (1960), Steenis (1972), Whitmore (1975), Hartley (1986) and Thorne (1986)]. Floristic connections to the temperate latitudes are especially apparent in Kaijende's montane bogs, which are essentially displaced temperate-continental communities.

Ericaceae is the most diverse woody family in habitats above 3,000 m (Photos 43–45). Two of its principal genera,

Rhododendron and *Vaccinium*, are represented entirely by taxa restricted to New Guinea, most of these having ranges extending over large areas of the Central Divide (e.g. *Rhododendron beyerinckianum*, *R. commonae*, *R. herzogii*, *R. inconspicuum*, *R. macgregoriae*, *R. scabridibracteum*, *Vaccinium amblyandrum*, *V. finisterrae*, and *V. reticulato-venosum*; Photos 46–49). Similar patterns of island-wide endemism are also exemplified by Elaeocarpaceae (all recorded taxa), *Epilobium* (all recorded species), Myrsinaceae (all recorded taxa), *Olearia* (all species except *O. pallida*), Orchidaceae (most taxa; see Vogel and Schuiteman in press), *Rubus* (all species except the indigenous *R. moluccana*), Theaceae (all recorded species), and Winteraceae (all recorded species). The remainder of Kaijende's montane flora is generally comprised of plants distributed through at least two provinces (e.g. *Vaccinium apiculatum*, *V. auriculifolium*, *V. schoddei*). Notwithstanding the new species discovered on the RAP survey, localized endemics like *Solanum nolense* are an exception.

The overall paucity of geographically restricted taxa is consistent with New Guinea's Quaternary history of climatic and floristic change. During the last glacial age from 22,000 to 10,000 yrs BP, the alpine and subalpine zones were forced downwards to elevations below 2,500 m (Hope 1976a). As part of this adjustment, treelines were depressed by 1,200 m (Hope 1973) and may have stabilized at 2,000–2,300 m throughout the cordillera until ca. 12,000 yrs BP (Powell and Hope 1976). At Tari and Koroba, palynological cores from 30,000+ yrs BP show signs of upper montane species occurring as low as 1,500 m, clearly implying a dramatic shift in vegetation belts (Hope 1976a). Previous glacial periods during the Pleistocene were at least as severe, being accompanied by extension of subalpine formations into habitats where beech is now dominant. In some areas, *Nothofagus* forests probably reached 1,400 m, far below their contemporary centers (Gillieson et al. 1989). Climatically induced displacements of such magnitude would have connected different summits on the Divide through extension of their montane vegetation, a process nowadays reflected in the relative scarcity of local endemics and the higher incidence of wider-area endemism.

An obvious consequence of past climatic change is that the principal features of the Kaijende flora have only been determined within the last 15,000 years, primarily during the interglacial recovery of vegetation zones. For higher elevation sites like Omyaka, the existing community mosaic would have established more recently, at 8,000–9,000 yrs BP, according to pollen sequences at comparable elevations on Mt. Wilhelm (see timeline in Hope 1976a). Kaijende montane formations are thus relatively youthful floristic environments, having migrated into their present positions with the Holocene lifting of forest zones. It is very unlikely that the botanical novelties discovered by the survey evolved in situ. More probably the new plants originated at lower elevations and moved with the vegetation belts during the post-ice age amelioration of climate. The alternative scenario, of acceler-

ated local speciation occurring within the Holocene period, seems less plausible, given the overall scarcity of geographically restricted Highland endemics.

Certain parts of the Kaijende flora may still be reassembling at their contemporary stations. Because events of the past several thousand years have required fairly rapid extensions in range, it is unlikely that the flora of the region has been able to adjust in real time. A floristic lag effect is probable, and its existence can be inferred from the spatial heterogeneity of Kaijende-area forests, in particular by the very dissimilar species compositions and frequencies between ecologically equivalent sites (e.g. at Omyaka and areas west of Porgera Reservoir). UMF formations in the Kaijende region are arguably in a state of ongoing reconstitution at the higher elevations, and the equilibrium of the climatic-climax forest has not yet been achieved.

Many aspects of Holocene forest change remain poorly understood. Few studies have been undertaken on New Guinea paleoenvironments since the pioneering work of the 1970s, and although patterns of vegetation change at the upper elevations seem clear enough, corresponding events at lower elevations are largely conjectural.

Thus while there is no question that floristic environments at Kaijende have been profoundly destabilized in the last 15,000 years, it is less clear whether these influences extended over the entire conservation district. The lower parts of the proposed WMA fall within the potential elevational limits of forest replacement as determined from palynological studies at other sites. But whether or not the ice age expansion of subalpine conditions descended to the lower edges of the Kaijende tract remains unknown. In this connection it is interesting to note that the depositional-basin lakes and swamps at Lake Tawa (2,200 m) are coincidentally positioned at the reconstructed contact between the paleohistorical UMF and LMF (2,200–2,500 m; see Hope 1976a: figure 11). Stratigraphic and palynological analysis of sediment cores from Lake Tawa could prove highly illuminating.

An anthropogenic origin for the tree fern savanna?

The *Cyathea* savanna is unique to the island of New Guinea and has consequently attracted widespread attention as one of Papuasia's classic floristic environments (Photo 50). Due to its visually appealing qualities, the savanna has been a frequent subject of photographic depiction [inter alia Holtum 1963: 107 (showing *C. dicksonioides*), 129–130 (from Enga's Sugarloaf, with *C. atrox* var. *inermis*), Mangen 1993: 77 (as 'treefern shrubland' from Mt. Trikora), Paijmans 1976: 89 (same as Holtum but with a wider visual field), Wade and McVean 1969]. At Kaijende this formation is exceptionally well developed, comprising one of the largest and most conspicuous landscapes in the upper montane zone from 3,000 m to at least 3,400 m. In other montane areas, the savanna attains its best development from 2,700–3,300 m elevation (Paijmans 1976).

Unlike other vegetation types at Kaijende, there is considerable disagreement over the ecological status of the savanna-grassland. The prevailing view is that nearly all Papuan grasslands (with the notable exception of occurrences at or above treeline) are of anthropogenic origin (Hammermaster and Saunders 1995a). Paijmans (1976) for example, regarded *Cyathea* savanna as a fire disclimax, recognizing the apparent role played by anthropogenic burning in the creation and maintenance of open grassy areas. This interpretation of the savanna as a secondary vegetation derived from former forest was also adopted by Brass (1941) and by Wade and McVean (1969).

The effects of fire during periods of drought have been described by many observers (e.g. White 1975, Paijmans 1976, Hope 1983, Johns 1986). The Omyaka vegetation has clear evidence of such influences, with charred logs and tree stumps scattered through the forest-grassland transition in many places near the former camp-site. According to a local guide, the savanna and scrub mosaic centered on 05°31'28" S, 143°03'12" E (Photo 51) was burned in 1998 during the last El Niño event. It is likely that fires set by travellers passing through the vicinity have been a frequent occurrence in the past, and that burning is not restricted just to periods of severe drought. The highly irregular forest-grassland boundary in this general area, and its typical configuration as tongues and strips apparently shaped by wind, are very suggestive of fire etiology.

Although the present-day spatial correspondences between burning and *Cyathea* savanna are unequivocal, this connection does not preclude a natural origin for such communities. Based on paleohistorical reconstruction from pollen diagrams, Hope (1976a) concluded that large expanses of treefern savanna were present on Highlands summits prior to 10,000 yrs BP, and may have even extended above treeline to form communities for which there is no longer any existing analogue.

On this interpretation the relationship between fire and *Cyathea* savanna is not a cause and effect connection, but more akin to facilitation: anthropogenic burning favoring the spread of a natural community because of the inherent fire tolerance of its components. If the *Cyathea* grasslands were indeed present at a time when human influence can be discounted, the characterization of such areas as anthropogenic artefacts is overthrown. However the natural-status argument is not without uncertainties of its own. Palynological reconstruction is highly inferential; the determination of pollen spectra in sediment stratigraphies is affected by many factors and assumptions that cannot be precisely quantified (Tauber 1965, Faegri 1966, Faegri et al. 1989). In view of the conspicuous lack of consensus from past debate, the status of these intriguing landscapes is best regarded as remaining unresolved, even though their apparent restriction to New Guinea seems to favor the natural origin hypothesis. *Cyathea* is a common genus in other Malesian habitats where fires also occur, yet the treefern savanna facies has not been recorded elsewhere in the region. If such areas are the

result of disturbance, it is difficult to see why the presumed causative process has failed to generate the same response in apparently equivalent situations.

CONSERVATION RECOMMENDATIONS

Botanical imperatives for a Kaijende conservation district

Environmentalists understandably emphasize biotic criteria in the selection of proposed conservation easements. Often-times the practical aspects of reserve management receive scant attention from enthusiastic scientist-administrators, yet the commonplace non-biological issues relating to site accessibility, ambiance, operational costs etc., will often determine the viability of medium- and long-term activities within such tenements. Every existing protected area can boast of the presence of new and endemic taxa within their areas of oversight. The proposed Mt. Kaijende Highlands Conservation Area will be no different. However for planning purposes, it is more useful to consider the potentially unique aspects of a Kaijende initiative relative to the many Wildlife Management Areas (WMAs) already in existence.

What exactly are the potential advantages of a Kaijende conservation project for botany? And in what way(s) will the establishment of yet another conservation zone provide opportunities beyond what is already available elsewhere? In any retrospective analysis of what has been learned during the recent survey, these should be the summary points deserving of explicit enumeration, beyond the mere discussion of taxonomic discoveries made by RAP reconnaissance:

1. Kaijende environments are disproportionately represented by upper montane habitats and vegetation formations that are not protected by existing initiatives in Papua New Guinea. Island endemism is higher in UMF and subalpine environments than in low elevation habitats of the sort covered by many WMAs. Insofar as conservation should be focused on the preservation of unique biotic assets, the Kaijende Highlands plan is well placed to provide security for endemic taxa presently excluded from conservation consideration.

The biogeographic profile of the Kaijende flora differs markedly from lowland and colline conservation districts where the vegetation is primarily of tropical composition. Although Kaijende communities are species-depauperate, they include many plants found only in the highest parts of the Central Cordillera. Because of the elevation constraints, taxonomic and biogeographic studies involving these taxa can only be pursued in areas like the Waile Creek-Omyaka tract.

For similar reasons, Kaijende's montane habitats are especially appropriate for monitoring long-term floristic change caused by global warming. The UMF is acutely responsive to temperature shifts induced by climatic change, as demonstrated by palynological evidence from Holocene sediments. Baseline studies could be established to exploit Kaijende's

geographic advantages, in recognition of opportunities that cannot be replicated at other localities.

2. Not unexpectedly, summit environments in the Dividing Ranges are typically among the most remote and logistically challenging environments in New Guinea. Service infrastructures are very poor or nonexistent in such places, with the unfortunate result that many upper montane habitats remain inadequately known despite their intrinsic botanical value.

The Kaijende survey illustrates the potential rewards of working in habitats where access and support facilities are of a quality commensurate with the biotic value of a site. Every protected area (in PNG mostly WMAs) has biodiverse environments in an exemplary state of preservation, otherwise the conservation imperative for those areas would not have arisen in the first place. However few localities can offer the same advantages of accessibility and facilities support provided by current operations at Porgera mine. The survey's successes were in large part attributable to the infrastructural resources present in the surrounding district. There is ample reason for anticipating that future scientific activities could be enhanced to the same extent as the recent undertaking.

3. Kaijende habitats are scenic and visually stunning landscapes. Their picturesque qualities cannot be reduced to objective argumentation in the manner of taxonomic discovery, but aesthetic considerations should be as much a part of site evaluation as the more conventional aspects of RAP appraisal. The landscape panoramas at Omyaka and Lake Tawa are among the most photogenic ever experienced by the assessment team. While many conservation districts are characterized by gloomy forests laden with pests and parasites, the Kaijende localities are comparatively pleasant and easy environments for exploration and research. The upper montane areas are often cold and misty (there was a hail fall on August 22 and daytime temperatures typically averaged a chilly 5° C), but on balance there are few conservation venues in PNG as amenable to recreational and study activities.

Mine-site rehabilitation

As PJV enters the final phase of operations at Porgera, activities relating to corporate withdrawal will become of increasingly greater urgency. The adoption and implementation of a reforestation strategy for areas impacted by the mine will undoubtedly be of particular concern.

A logical way of proceeding on this issue is to first identify the components of floristic succession in nearby environments, and to then apply these processes to the exit plan. Floristic indigens should receive preferential attention in such an endeavor, instead of importing alien plants that may or may not prove suitable as mine-site colonizers. By the very fact of their presence in endemic communities, local species will be the most adaptable to Porgera conditions. The least desirable action that PJV could undertake is to introduce

potentially invasive species which later act as seed sources for contamination of the conservation tract. Many Kaijende habitats are open-aspect successional environments presenting opportune targets for invasion. The UMF and adjacent formations are presently in relatively unspoiled condition. Although 16 alien species were registered from habitats above 3,000 m, the non-native flora is primarily confined to roadsides and other avenues of human entry (Photos 52–53). Only two adventives were seen at Lake Tawa. Since the conservation initiative is proceeding under PJV auspices, the counterproductive nature of unintended impacts is self-evident.

Seral environments near Porgera are dominated by woody species from four genera: *Olearia* (six spp.), *Saurauia* (five spp.), *Symplocos* (one sp. with three vars.) and *Vaccinium* (eight spp.). Although other volunteer taxa are present in newly cleared sites (e.g. *Glochidion*, *Omalanthus*, *Macaranga*, and *Mallotus*) these are decidedly less prominent in terms of area coverage and frequency.

Reforestation trials should assess the suitability of all common pioneers, but the naturally dominant volunteers will be the most promising initial candidates in any revegetation exercise (Photos 54–60). For purposes of planning orientation, project principals should examine regrowth areas at the Pass (05°32'13" S, 143°04'59" E), where the candidate genera (*Olearia*, *Saurauia*, *Symplocos*, *Vaccinium*) are conspicuous invaders of quarry-rock rubble, clearly showing that the taxa involved do not require mineralized substrate for establishment. A similar capability for colonizing bare ground is also seen in several vining species; viz. *Gonocarpus halconensis*, *Muehlenbeckia monticola* (Photo 61), and especially the many species of montane *Rubus* found in grasslands and forest margins. The last genus however, is represented by unpleasantly thorny plants and would be less desirable as a designed groundcover.

The arborescent species of potential value in mine-site restoration can be extracted from Appendix 2. Among the entries on that list, *Symplocos cochinchinensis* requires separate consideration for its taxonomic and ecological variability. This species, more than any other in Papuasia, occurs in a confusing continuum of entities extending from sea-level to tree-line, and will probably exhibit a complementary range of ecological tolerances for specific site conditions. It may be possible to select for ecotypes pre-adapted to PJV environmental requirements, drawing from the wide assortment of forms seen at Kaijende.

The likelihood of clinal variation should be incorporated into the provenance trials for *Symplocos* outplant selection. Of the three varieties on the survey checklist, var. *orbicularis* is the most common, but is centered at elevations about 1,000 m above the mine site. The nominate variety and var. *monticola* are probably more suitable choices for revegetation at Porgera itself. It is appropriate to note that varietal distinctions cannot be consistently applied to individual plants, and numerous intermediates will defy classification (Nooteboom 1975, 1977). Provenance testing should examine the full

suite of Porgera-area morphotypes, irrespective of how they fit into the existing taxonomy.

The success of the restoration program will be ultimately dependent on recreating the patch dynamics responsible for long-term stability in most forest communities. Even-aged stands are intrinsically unstable because cohorts of identical age will progress through their maturational stages in synchrony, and will senesce simultaneously at the end of their life cycle. This process has been examined on ecosystem scales in environments where the forest canopy is monodominant and composed of single-generation cohorts (most notably in Hawaii forests: Gerrish and Mueller-Dombois 1980, Mueller-Dombois 1986). Unless an attempt is made to establish a self-sustaining community whose members are not one-generational, a population crash of the reforested areas will eventually occur.

Concerns relating to social and corporate responsibility are outside the scope of RAP assessment. But even so, the design of truly effective mitigative strategies will require thoughtful consideration of the factors governing community stability. Many site restoration programs are actually small-scale plantations, a circumstance which virtually ensures future instability. As noted before, the long-term success of a restored vegetation is best achieved by duplicating natural patterns, and this entails deliberate establishment of spatial, taxonomic, and demographic heterogeneity in the reconstructed communities.

Recommendations for future work

There is considerable scope for future inquiry. RAP biologists are merely a point element in conservation, and an 18-day reconnaissance can only provide a broad sketch of potentially fruitful directions. Much of the work done by the floristic team occurred in the high elevation zone above 3,000 m, which is probably the least speciose environment at Kaijende. From the insights obtained thus far, even better outcomes are likely if future activity is shifted to the south, against the border with Southern Highlands Province, and in the lowest parts of the conservation easement. Diversity will increase in step with elevation reduction. The vegetation below 2,000 m, where ice age perturbations would have been of lesser severity (the 2,200 m contour is the lower limit of a paleohistorical ecotone) should receive preferential attention. These lower montane habitats may have acted as Quaternary refugia for the oldest elements of the Kaijende flora. Even during the degenerative phases of former glacial maxima, plant communities could have retained a continuity in time and space at the lower elevations, while upland environments near Omyaka and Porgera were experiencing wholesale upset and replacement. Correspondingly greater opportunities for taxonomic discovery can be expected in the lower parts of the district, although operations there will not be easy because of the distance from logistical centers.

Because an overwhelmingly large portion of the proposed protected area lies above 2,000 m, additional conservation benefits could be realized by lowering the elevational bound-

ary of the Conservation Area to 1,500 m. The best way of achieving this is by extending the proposed easement to the west, into the Pori drainage (Southern Highlands Province). Biotic imperatives have no correlation to political or administrative lines, and paleohistorically stable environments are likely to be inadequately represented if the protected area is confined to Enga Province. Although sociopolitical constraints may effectively prevent such an extension, a 500 m addition in altitudinal range would make a significant contribution to the protected area's floristic coverage.

The pinnacle karst habitats near Porgera are deserving of future investigation and should preliminarily be accorded a high conservation priority. With sheer-faced ridges and razor-like summits, pinnacle limestone is one of the most spectacular topographies in the Malesian tropics. Within PNG the only examples of this geological formation (also known as arete or doline karst) are restricted to the Porgera subdistrict (Löffler 1977). The characteristic knife-edged appearance of the doline facies is particularly striking in aerial perspective (Photo 62). With the discovery of three new plants on the Lake Tawa limestone, the doline occurrences are logical targets for future exploration, despite the difficult logistics involved in their study.

REFERENCES

- Airy Shaw, H. K. 1980. The Euphorbiaceae of New Guinea. Kew Bull. Addit. Series 8. Her Majesty's Stationery Office. London.
- Angiosperm Phylogeny Group. 1998. An ordinal classification for the families of flowering plants. *Ann. Miss. Bot. Gard.* 85(4): 531–553.
- Angiosperm Phylogeny Group. 2003. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II. *Linnean Society of London. Bot. J. Linn. Soc.* 141: 399–436.
- Australian Survey Corps. 1979. Papua New Guinea 1:100,000 Topographic Survey Map. Edition 1-AAS, Series T601: Koroba 7486.
- Barthlott, W., W. Lauer and A. Placke. 1996. Global distribution of species diversity in vascular plants: towards a world map of phytodiversity. *Erdk. Arch. wiss. Geog.* 50: 317–327.
- Barthlott, W., J. Mutke, D. Rafiqpoor, G. Kier and H. Kreft. 2005. Global centers of vascular plant diversity. *Nova Acta Leop.* NF. 92(342): 61–83.
- Beehler, B. and L. E. Alonso (eds.). 2001. Southern New Ireland, Papua New Guinea: A Biodiversity Assessment. RAP Bulletin of Biological Assessment 21. Conservation International. Washington, DC.
- Brass, L. 1941. The 1938–39 expedition to the Snow Mountains, Netherlands New Guinea. *J. Arn. Arb.* 22: 271–342.
- Coode, M. J. E. 1981. Elaeocarpaceae. *In*: Henty, E. E. (ed.). *Handbooks of the Flora of Papua New Guinea*

- Vol. 2. Melbourne University Press. Carlton, Victoria. Pp 38–185.
- Craven, L. 1979. Eight new species of *Homalium* (Flacourtiaceae) from Papuaia. *Brunonia* 2(1): 107–124.
- Croft, J. R. 1986. Keys to the genera of pteridophytes in Papuaia. Unpublished manuscript, Lae National Herbarium.
- Davis, S. D., V. H. Heywood and A. C. Hamilton (eds.). 1995. Centres of Plant Diversity: A Guide and Strategy for Their Conservation. Vol. 2: Asia, Australia and the Pacific. IUCN Publications Unit. Cambridge, UK.
- Diels, L. 1922. Die Dilleniaceen von Papuaia. *Bot. Jahrb.* 57: 436–459.
- Faegri, K. 1966. Some problems of representativity in pollen analysis. *Paleobotanist* 15: 135–140.
- Faegri, K., P. E. Kaland and K. Krzywinski. 1989. Textbook of Pollen Analysis. J. Wiley and Sons. New York.
- Forster, P. I. 1995. Circumscription of *Marsdenia* (Asclepiadaceae: Marsdenieae), with a revision of the genus in Australia and Papuaia. *Austr. Syst. Bot.* 8: 703–933.
- Frodin, D. G. 1990. Botanical progress in Papuaia. In: Baas, P., K. Kalkman, and R. Geesink (eds.). *The Plant Diversity of Malesia, Proceedings of the Flora Malesiana Symposium Commemorating Prof. Dr. C.G.G.J. van Steenis*. Kluwer Academic Publishers. Dordrecht, Netherlands. Pp 235–247.
- Gardner, R. O. 2002. The genus *Coprosma* (Rubiaceae) in New Guinea. *Candollea* 57: 97–130.
- Gerrish, G. and D. Mueller-Dombois. 1980. Behavior of native and non-native plants in two tropical rain forests on Oahu, Hawaiian Islands. *Phytocoenologia* 8: 237–295.
- Gillieson, D., G. Hope and J. Luly. 1989. Environmental change in the Jimi Valley. In: Gorecki, P. and D. Gillieson (eds.). *A Crack in the Spine*. James Cook University. Townsville. Pp 105–122.
- Gillison, A. N. 1970. Structure and floristics of a montane grassland/forest transition, Doma Peaks region, Papua. *Blumea* 18(1): 71–86.
- Good, R. 1960. On the geographical relationships of the angiosperm flora of New Guinea. *Bull. Br. Mus. Nat. Hist. Botany* 2: 205–226.
- Grubb, P. J. and P. F. Stevens. 1985. The forests of the Fatima Basin and Mt. Kerigomna, Papua New Guinea: with a review of montane and subalpine rainforests in Papuaia. Research School of Pacific Studies, Publ. BG/5. Australian National University. Canberra.
- Hammermaster, E. T. and J. C. Saunders. 1995a. Forest Resources and Vegetation Mapping of Papua New Guinea. PNGRIS Publ. 4. CSIRO and AIDAB. Canberra.
- Hammermaster, E.T. and J.C. Saunders. 1995b. Forest Resources and Vegetation Mapping of Papua New Guinea. 1:250,000 vegetation map overlays separately issued as working copies to PNGRIS Publ. 4. CSIRO and AIDAB. Canberra.
- Hartley, T. G. 1974a. A revision of the genus *Acronychia* (Rutaceae). *J. Arn. Arb.* 55(3): 469–523.
- Hartley, T. G. 1974b. A revision of the genus *Acronychia* (Rutaceae). *J. Arn. Arb.* 55(4): 525–567.
- Hartley, T. G. 1986. Floristic relationships of the rainforest flora of New Guinea. *Telopea* 2(6): 619–630.
- Hartley, T. G. and L. M. Perry. 1973. A provisional key and enumeration of species of *Syzygium* (Myrtaceae) from Papuaia. *J. Arn. Arb.* 54(2): 160–227.
- HDOA (Hawaii Department of Agriculture). 1992. List of Plant Species Designated as Noxious Weeds for Eradication or Control Purposes. Hawaii Department of Agriculture. Hawaii.
- Holtttum, R. E. 1959. Keys to the genera of Pteropsida. *Flora Malesiana ser. II.* 1(1): xv–xxi.
- Holtttum, R. E. 1963. Cyatheaceae. *Flora Malesiana ser. II.* 1(2): 65–176.
- Holtttum, R. E. 1973. Studies in the family Thelypteridaceae V. The genus *Pneumatopteris* Nakai. *Blumea* 21: 293–325.
- Holtttum, R. E. 1978. *Lomariopsis* group. *Flora Malesiana ser. II.* 1(4): 255–330.
- Holtttum, R. E. 1981. Thelypteridaceae. *Flora Malesiana ser. II.* 1(5): 331–599.
- Hoogland, R. D. 1958. The alpine flora of Mt. Wilhelm (New Guinea). *Blumea Suppl.* IV, Dr. H. J. Lam Jubilee Vol. 2 X: 220–238.
- Hope, G. S. 1973. The Vegetation History of Mt. Wilhelm, Papua New Guinea. Unpublished Ph.D. thesis. Australian National University. Canberra.
- Hope, G. S. 1976a. The vegetational history of Mt. Wilhelm, Papua New Guinea. *J. Ecol.* 64: 627–663.
- Hope, G. S. 1976b. Vegetation. In: Hope, G. S., J. A. Peterson, U. Radok, and I. Allison (eds.). *The Equatorial Glaciers of New Guinea. Results of the 1971–1973 Australian Universities' Expeditions to Irian Jaya: Survey, Glaciology, Meteorology, Biology and Palaeoenvironments*. A. A. Balkema. Rotterdam. Pp 113–172.
- Hope, G. S. 1983. The vegetational changes of the last 20,000 years at Telefomin, Papua New Guinea. *Sing. J. Trop. Geogr.* 4: 25–33.
- Hovenkamp, P. H. 1998a. An account of the Malay-Pacific species of *Selliguea* (Polypodiaceae). *Blumea* 43: 1–108.
- Hovenkamp, P. H. 1998b. *Selliguea*. *Flora Malesiana ser. II.* 3: 175–231.
- Johns, R. J. 1977 (reprinted 1984). *The Vegetation of Papua New Guinea. Part 1: An Introduction to the Vegetation*. PNG Office of Forests. Bulolo.
- Johns, R. J. 1986. The instability of the tropical ecosystem in New Guinea. *Blumea* 31(2): 341–371.
- Johns, R. J. and P. F. Stevens. 1971 (reissued 1974). *Mount Wilhelm flora: A checklist of the species*. *Botany Bull.* 6. Div. of Botany, Dept. of Forests, Papua New Guinea. Lae.

- Kalkman, C. 1987. The genus *Rubus* (Rosaceae) in Malesia. 3. The subgenus *Micranthobatus*. *Blumea* 32(2): 323–341.
- Kalkman, C. and W. Vink. 1970. Botanical exploration in the Doma Peaks region, New Guinea. *Blumea* 18(1): 87–135.
- Koster, J. Th. 1966. The Compositae of New Guinea I. *Nova Guinea, Botany* 24: 497–614.
- Koster, J. Th. 1975. The Compositae of New Guinea IV. Additions and corrections to I, II, and III. *Blumea* 22(2): 207–217.
- Laubenfels, D. J. de. 1988. Coniferales. *Flora Malesiana ser. I.* 10(3): 337–453.
- Löffler, E. 1977. *Geomorphology of Papua New Guinea*. CSIRO and Australian National University Press. Canberra.
- Mack, A. (ed.). 1998. *A Biological Assessment of the Lakekamu Basin, Papua New Guinea*. RAP Working Papers Number 9. Conservation International. Washington, DC.
- Mack, A. and L. E. Alonso (eds.). 2000. *A Biological Assessment of the Wapoga River Area of Northwestern Irian Jaya, Indonesia*. RAP Bulletin of Biological Assessment Number 14. Conservation International. Washington, DC.
- Mangen, J. M. 1993. *Ecology and Vegetation of Mt. Trikora, New Guinea (Irian Jaya/Indonesia)*. Travaux Scientifiques du Musée National D'Histoire Naturelle de Luxembourg. Luxembourg.
- Merrill, E. D. and L. M. Perry. 1943. *Plantae Papuanae Archboldianae*, XI. *J. Arn. Arb.* 24(1): 34–59.
- Merrill, E. D. and L. M. Perry. 1946. *Plantae Papuanae Archboldianae*, XVII. *J. Arn. Arb.* 27(2): 193–233.
- Mueller-Dombois, D. 1986. Perspectives for an etiology of stand-level dieback. *Ann. Rev. Ecol. Syst.* 17: 221–243.
- Nooteboom, H. P. 1975. Revision of the Symplocaceae of the Old World, New Caledonia Excepted. *Leiden Botanical Series 1*. Leiden University Press. Netherlands.
- Nooteboom, H. P. 1977. Symplocaceae. *Flora Malesiana ser. I.* 8(2): 205–274.
- Paijmans, K. 1975. *Explanatory Notes to the Vegetation Map of Papua New Guinea*. Land Research Series 35. CSIRO. Melbourne.
- Paijmans, K. (ed.). 1976. *New Guinea Vegetation*. CSIRO and Australian National University Press. Canberra.
- Parris, B. S. In press. Chapter 3. Floristics: ferns and fern allies. *In: Marshall, A. and B. M. Beehler, (eds.). The Ecology of Papua*. Periplus Editions. Singapore.
- Philipson, W. R. 1978. A synopsis of the Malesian species of *Polyscias* (Araliaceae). *Blumea* 24(1): 169–172.
- Philipson, W. R. 1979. Araliaceae-I. *Flora Malesiana ser. I.* 9(1): 1–105.
- Philipson, W. R. 1982. A revision of the Malesian species of *Palmeria* (Monimiaceae-Monimieae). *Blumea* 28(1): 85–101.
- Powell, J. M. and G. S. Hope. 1976. Vegetation history. *In: Paijmans, K. (ed.). New Guinea Vegetation*. CSIRO and Australian National University Press. Canberra, Australia. Pp 101–104.
- Reeder, J. R. 1946. Notes on Papuasian Saxifragaceae. *J. Arn. Arb.* 27(3): 275–288.
- Royen, P. van. 1982. *The Alpine Flora of New Guinea*. Volume 3: Taxonomic Part Winteraceae to Polygonaceae. J. Cramer. Vaduz.
- Saunders, J. C. 1993a. *Forest Resources of Papua New Guinea*. Color maps (4) at 1:1,000,000 scale. PNGRIS Publication 2. CSIRO. Canberra.
- Saunders, J. C. 1993b. *Forest Resources of Papua New Guinea*. Explanatory Notes to Map. PNGRIS Publication 2. CSIRO and Australian International Development Assistance Bureau. Canberra.
- Sleumer, H. 1967. Ericaceae. *Flora Malesiana ser. I.* 6(5): 669–914.
- Sleumer, H. 1986. A revision of the genus *Rapanea* Aubl. (Myrsinaceae) in New Guinea. *Blumea* 31(2): 245–269.
- Smith, A. C. 1941. Studies of Papuasian plants, IV. *J. Arn. Arb.* 22(1): 497–528.
- Sohmer, S. H. 1988. The nonclimbing species of the genus *Psychotria* (Rubiaceae) in New Guinea and the Bismarck Archipelago. *Bishop Mus. Bull. Bot.* 1. Bishop Museum Press. Honolulu.
- Steenis, C. G. G. J. van. 1972. *The Mountain Flora of Java*. E. J. Brill. Leiden, Netherlands.
- Steenis, C. G. G. J. van. 1982. Addenda, corrigenda et emendanda. *Flora Malesiana ser. I.* 9: 553–573.
- Stevens, P. F. 2004. New taxa in *Paphia* and *Dimorphanthera* (Ericaceae) in Papuasias and the problem of generic limits in Vaccinieae. *Edinb. J. Bot.* 60: 267–298.
- Supriatna, J. (ed.). 1999. *The Irian Jaya biodiversity conservation priority-setting workshop*. Final report. Conservation International. Washington, DC.
- Symon, D. E. 1985. The Solanaceae of New Guinea. *J. Adelaide Bot. Gard.* 8: 1–171.
- Takeuchi, W. 1999a. Botanical results from the 1995 Bismarck-Ramu expedition in Papua New Guinea. *Sida* 18(3): 751–782.
- Takeuchi, W. 1999b. New plants from Crater Mt., Papua New Guinea, and an annotated checklist of the species. *Sida* 18(4): 961–1006.
- Takeuchi, W. 2003. Botanical summary of a lowland ultrabasic flora in Papua New Guinea. *Sida* 20(4): 1491–1559.
- Takeuchi, W. 2005. Botanical results from a floristic survey of montane environments within the PNG Gas Project area. *Environmental Impact Statement Volume 1. Main Report*. Report CR 790-20-Rev4. Esso Highlands Ltd. and Enesar Consulting Pty. Ltd.
- Takeuchi, W. 2007. Notes on *Acronychia* (Rutaceae) from the Kaijende Highlands of Papua New Guinea. *Harv. Pap. Bot.* 11(2): 203–206.

- Takeuchi, W. and M. Golman. 2001. Botanical documentation imperatives: some conclusions from contemporary surveys in Papuasias. *Sida* 19(3): 445–468.
- Takeuchi, W. and J. Wiakabu. 2001. A transect-based floristic reconnaissance of Southern New Ireland. *In*: Beehler, B. and L. E. Alonso, (eds.). Southern New Ireland, Papua New Guinea: A Biological Assessment. RAP Bulletin of Biological Assessment Number 21. Conservation International. Washington, DC. Pp 32–39, 73–88.
- Tauber, H. 1965. Differential pollen dispersion and the interpretation of pollen diagrams. *Geol. Surv. Den. II.* 89: 1–69.
- Thorne, R. F. 1986. Antarctic elements in Australasian rainforests. *Telopea* 2(6): 611–617.
- Verdcourt, B. 1979. A Manual of New Guinea Legumes. Division of Botany Bulletin 11. Kristen Press. Madang, Papua New Guinea.
- Vogel, E. and A. Schuiteman. In press. Chapter 3. Floristics: Orchidaceae. *In*: Marshall, A. and B. M. Beehler, (eds.). The Ecology of Papua. Periplus Editions. Singapore.
- Wade, L. K. and D. N. McVean. 1969. Mt. Wilhelm studies I. The alpine and subalpine vegetation. Dept. Biogeogr. & Geomorph., Research School of Pacific Studies, Publ. BG/1. Australian National University. Canberra.
- White, K. J. 1975. The effect of natural phenomena on the forest environment. Dept. of Forests. Port Moresby.
- Whitmore, T. C. 1975. The Rain Forests of South-East Asia. Clarendon Press. Oxford.
- Whitmore, T. C. 1980. *Macaranga*. *In*: Airy Shaw, H. K. The Euphorbiaceae of New Guinea. Kew Bull. Addit. Series 8. Her Majesty's Stationery Office. London. Pp 123–162.
- Wilde, W. J. J. O. de. 1972. Passifloraceae. Flora Malesiana ser. I. 7(2): 405–434.