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# Composition and structure of the cloud forest on Mt. Delaco, Gau, Fiji

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## Abstract

*The composition and structure of cloud forest on Mt. Delaco (715m), Gau, Fiji Islands, is investigated using a transect following a ridge. Diameter (dbh), height, epiphyte cover and distance to the nearest neighbour were measured for each plant of 5 or more cm in dbh. A total of 42 vascular species were identified. The canopy was 3-5m tall, with* Alpinia boia *reaching 7m in height. The tree fern* Dicksonia brackenridgei *dominated the vegetation, accounting for 56% of the total basal area.* Rapanea myricifolia, Hedycarya dorstenoides *and* Ascarina diffusa *were other common species. Epiphytes were abundant and epiphyte cover for most trees was more than 50%. The most common epiphytes were* Nephrolepis tuberosa *and* Nephrolepis saligna, Collospermum montanum, Peperomia *spp., mosses and filmy ferns (Hymenophyllaceae) were other common species. A species of* Freycinetia *was the dominant climber. There was a moderately strong correlation between epiphyte richness and dbh of the host species (r = 0.59). The limited literature on cloud forest in the tropical insular Pacific suggests that while many taxa are shared, the species composition may vary considerably on different mountains.*

## 1. Introduction

The Fiji Islands are an oceanic island group located between longitudes 177$^o$ W and 177$^o$ E and latitudes 15$^o$ to 22$^o$ S. The islands cover an ocean territory of about 650,000 km$^2$, of which less than 3% are land area. Of the more than 500 islands that compose the Fiji archipelago, Viti Levu (10,338 km$^2$) and Vanua Levu (5,535 km$^2$) are the largest and constitute more than 80% of the total landmass (Figure 1). Taveuni (434 km$^2$) and Kadavu (408km$^2$) are also of considerable size (Mueller-Dombois & Fosberg 1998). There are also many smaller islands, of which Gau with an area of 140km$^2$ is the largest (Watling, 1986).

Cloud forest, also called upper montane forest or tropical montane cloud forest (TMCF), is very susceptible to climatic changes (Still *et al.*, 1999). TMFC are characterised by stunted and gnarled tree growth, moss-covered trunks and abundance of tree ferns and epiphytes (Osborne, 2000). They experience a temperature range of 10 ºC to 20 ºC and non-seasonal total annual rainfall of more than 3,500 mm (Watling and Gillison, 1993). TMCF are also major interceptors of horizontal precipitation and hence of major importance in the hydrological cycle (Merlin and Juvik, 1993; Still *et al*., 1999; Hölscher *et al*., 2004; Holder, 2004).

The richness and abundance of epiphytes is greater in the TMCF than in other rain forest types (Wolf, 2003; Küper *et al.*, 2004; Cardelús *et al*., 2006). Epiphyte diversity seems to increase with the diameter at breast height (dbh) of the host tree and is also related to bark characteristics such as bark thickness and water retention capacity (Mehltreter *et al*., 2005; Flores-Palacios and García-Francos, 2006). Larger epiphytes often create tiny biomes that have their own fauna and are important for the retention of atmospheric nutrients and as substrate for wildlife foraging (Nadkarni *et al.*, 2004). While the persistent cloudiness and interception of cloud water favours epiphytes, it limits photosynthesis, partially explaining the stunted growth of TMCF trees (Letts and Mulligan, 2005). In Fiji, TMCF has a unique flora (Gibbs, 1909; Smith, 1979-1996) and has been identified as one of nine principal vegetation types, occurring at mountaintops and ridges above 600m near the coast and at those above 900m inland (Mueller-Dombois and Fosberg, 1998) or as low as 450m on smaller islands (Merlin and Juvik, 1993). Fiji TMCF are restricted to higher islands and have to date only been reported from Viti Levu, Vanua Levu, Taveuni and Gau (Merlin and Juvik, 1993). In the TMCF on Mt Koroturanga (1,210m) on Taveuni, light intensity on the ridge top is reduced by 30% under cloud cover and average air temperature was about 10 $^{\circ}$C lower at 1,200 m compared to the lowlands (Ash, 1987).

Floristically, Fiji's TMCF harbour endemic species that are restricted to high altitudes and because of the wet and cool conditions, including some members of otherwise temperate families, such as *Paphia vitiensis* Seem. (Ericaceae). In Taveuni, 23 species were unique to the TMCF and most of the common trees in the lowland and upland rainforest did not penetrate into this forest (Ash, 1987). Watling and Gillison (1993) noted the similarity of the Fijian TMCF to that of Papua New Guinea and New Zealand, but also that it is ecological unique in the superabundance of tree ferns (species of *Cyathea*, *Leptopteris*) and climbing panadanus (species of *Freycinetia*).

While TMCF in Central and South America has been extensively studied, those in the tropical Pacific and Asia have received comparatively little attention, with the exception of the relatively species-poor TMCF in Hawaii (Berlin *et al*., 2000; Santiago, 2000). Indeed, Ash's (1987) account of TMCF on Taveuni remains the only published quantitative study on TMCF in the tropical insular Pacific outside Hawaii. This paper looks at the composition of cloud forest on Gau Island, the fifth largest island in Fiji. It aims to provide a preliminary species list for the TMCF of Gau and to relate this to TMCF in other Pacific countries. It also investigates the correlation between epiphytic richness and host tree dbh.

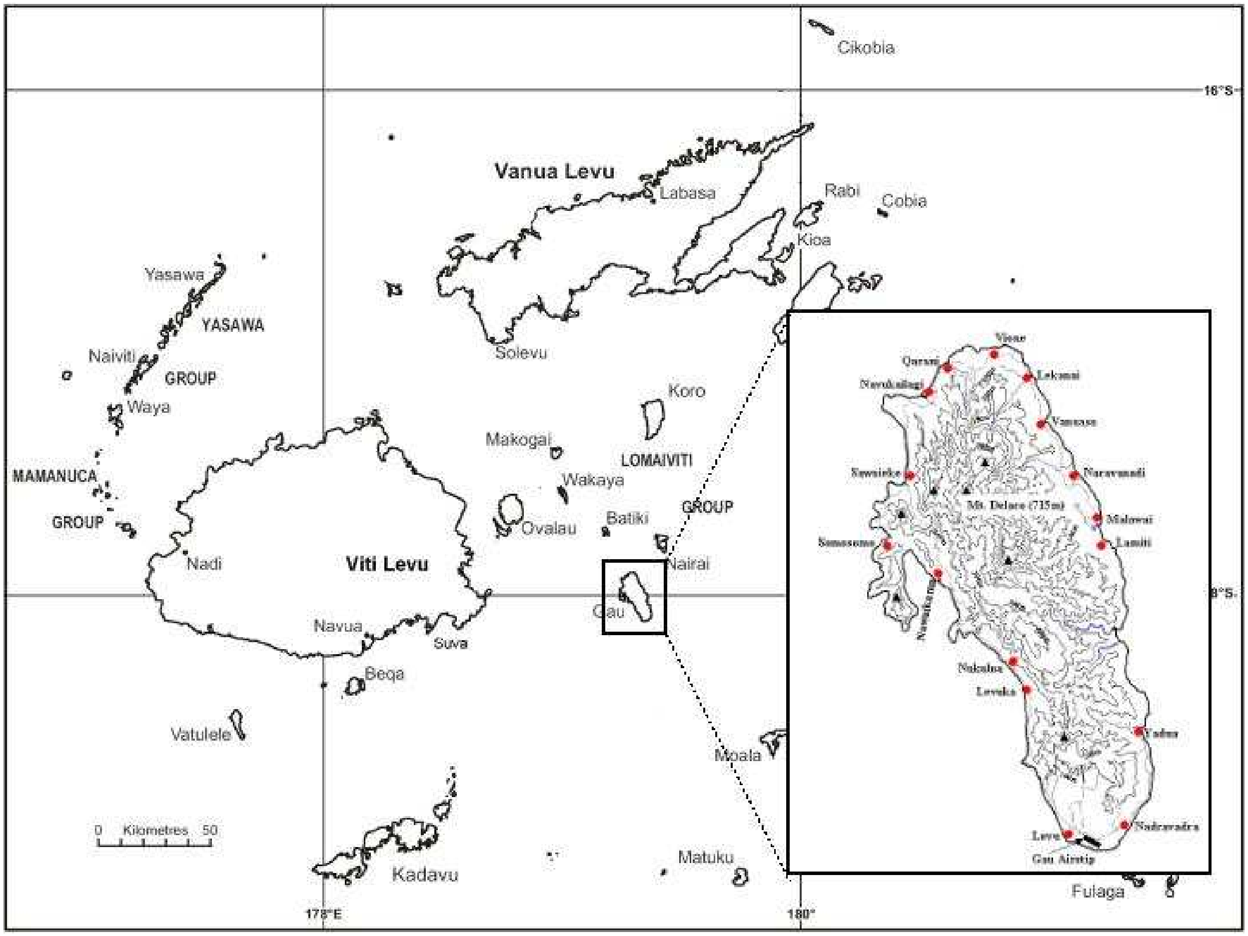


**Figure 1.** Map of the Fiji archipelago with an enlarged inset of Gau.

## 2. Materials and Methods

### 2.1 Study Site

Gau Island has an area of 140 km$^2$ with rugged topography and over 50 % of its rainforest are believed to be still intact. Cloud forest is restricted to the vicinity of the two highest peaks of the island, Mt. Delaco (715 m) and Mt. Delacoboni (705 m), in the north of the island (Watling and Gillison, 1993). Although no climatic data is available for the island of Gau, the prevalent Southeast tradewinds have certainly the major influence on the climate, producing high rainfall areas in mountainous regions and creating rain-shadows on the leeward side of the island (Keppel, unpubl. data).

### 2.2 Field Work

Because cloud forest is restricted to ridge tops of the highest mountains (Watling and Gillison, 1993), we used a modified version of the Wandering Quarter Method of vegetation sampling (Mueller-Dombois and Ellenberg, 2003), whereby we walked about 40m along a ridge top, measured the diameter at breast height (dbh) of host trees above 5cm dbh and recorded the cover of different epiphyte species using the Braun-Blanquet scale. We intended to sample a bigger area but after about 50m, there was a noticeable change in species composition. The specimens collected were identified and deposited at the South Pacific Regional Herbarium (SUVA).

## 3. Results

### 3.1 Flora

A total of 42 species were recorded, of which 17 (c. 40%) were endemic (table 1). The filmy ferns (Hymenophyllaceae) with 7 species (c. 17%) were the most diverse family, followed by the Davalliaceae and the orchids (Orchidaceae) with 4 species (c. 10%) each (see appendix 1). *Peperomia attenuata* var. *roseipica* (previously only known from two collections from mountains on Vanua Levu), *Cyrtandra victoriae* (previously assumed to be restricted to mountains and ridges of Viti Levu), and *Hoya megalantha* (previously collected from high mountains on Viti Levu, Vanua Levu, Taveuni and Kadavu) are for the first time reported from Gau. Mt. Delaco is the type locality for *Ascarina diffusa* and remains the only known locality for the species in Fiji.

Epiphytes accounted for almost half of the diversity (19 spp., 45%). Thirteen species (68%) of the epiphytes were ferns and fern allies, three (16%) were orchids, two pepperomias and one a member of the lily family. Trees and shrubs accounted for nine species (21%), lianas and hemiepiphytes for six species (14%) and terrestrial ferns (including two tree ferns) and herbs (including the only non-native species *Clidemia hirta* and the giant ginger *Alpinia boia*) for four (10%).

### 3.2 Vegetation

We counted 25 plants with a dbh greater than 5cm belonging to 9 species. The tree fern *Dicksonia brackenridgei* was the most common with 11 individuals (44%) and composing 56% of the total basal area. The vegetation is stunted with the canopy being about 3 to 5m in height (appendix 2). More than 70% of the plants with a dbh greater than 5cm have an epiphyte cover of more than 50% (values 4 and 5 on the Braun-Blanquet scale). The giant ginger, *Alpinia boia*, differs from other plant by growing slightly taller (to 7m) and having a low epiphyte cover (value 1 on the Braun-Blanquet scale).

*Nephrolepis tuberosa* (Davalliaceae) was the only epiphyte that was found on more than half of the 25 host trees studied (table 2). Other common epiphyte species were *Collospermum montanum* (Liliaceae), *Nephrolepis saligna* and two species in the genus *Peperomia* (Pepepromiaceae) and filmy ferns (Hymenophyllaceae). A species of *Freycinetia* (Pandanaceae) was the dominant climber, occurring on 12 of the 25 host trees, but could not be identified in the absence of flowers and fruits. *Epipremnum pinnatum* (Araceae) was found on eight of the host trees, *Psychotria parvula* (Rubiaceae) on three, while there was only a single plant of *Flagellaria indica* (Flagellariaceae) and *Hoya megalantha* (Asclepiadaceae).
A moderately strong correlation ($n$ = 25, $r$ = 0.59) was detected between the dbh of the host tree and the number of epiphytes. This relationship was somewhat stronger when only dicotyledonous trees were considered (n = 12, r = 0.67).

## 4. Discussion

Similar to Ash's (1987) study on Mt. Koroturaga, Taveuni, the height of the canopy on Mt. Delaco ranges from 5-7 m. Our results are the first to put quantitative values to the superabundance of tree ferns and *Freycinetia* described as characteristic for Fiji's cloud forests by Watling and Gillison (1993). On Mt. Delaco tree ferns, *Dicksonia brackenridgei*, accounts for more than 50% of the basal area and *Freycinetia* is found on about half of all the host trees.

Epiphytes reach high abundance and diversity in TMCF (Küper *et al*., 2004; Cardelús *et al*., 2006) and in our case epiphyte diversity accounted for almost half of all the species recorded. Our data also supports previous findings that epiphyte diversity increases with the dbh of the host tree (Flores-Palacios and García-Franco, 2006). Furthermore this correlation was stronger when tree ferns were excluded from the analysis ($r$ = 0.67 versus $r$ = 0.59 with tree ferns included), a phenomenon previously observed (Mehltreter *et al*., 2005).

Merlin and Juvik (1993) produced a list of "selected cloud forest taxa in the Pacific", which included "some of the more important, common, and/or unique woody plants found in Pacific Island TMCF" (pg.158). However, the list intentionally omitted herbaceous taxa such as filmy ferns (Hymenophyllaceae), orchids (Orchidaceae), *Collospermum* (Liliaceae) and *Peperomia* (Peperomiaceae), which are characteristic of Pacific Island TMCF. The tree fern *Dicksonia* (Dicksoniaceae) and the woody taxa *Cyrtandra* (Gesneriaceae) and *Astronidium* (Melastomataceae), which are common components of TMCF in Fiji and other Pacific countries (Brownlie, 1977; Whistler, 2002), were also not included in the list. We, therefore, present an expanded list (table 3) that includes the above-mentioned taxa. We have excluded *Paphia* (Ericaceae), which commonly occurs in the cloud forests of Fiji's largest island, Viti Levu, but is absent from other islands in the insular Pacific (Smith, 1981).

When comparing the only two available species lists for cloud forests in Fiji, only *Rapanea myricifolia* (Myrisinaceae) was shared between the Mt. Koroturaga (Ash, 1988) and Mt. Delaco (this study). Mt. Silisili on Savai'i in Samoa (Schuster *et al*., 1999) and Mt. Popomanaseu on Guadalcanal in the Solomon Islands (Corner, 1969) also have very different species compositions. Limited similarity between cloud forests on different mountains has also been observed on three isolated mountains on the Caribbean coast of Colombia and Venezuela (Sugden, 1983; Merlin and Juvik, 1993).

**Table 1.** Summary of the classification, origin and distribution of the species identified.

| | **Indigenous** | **Endemic** | **Introduced** |
|---|---|---|---|
| Ferns & Fern allies | 18 | 5 | 0 |
| Monocotyledons | 10 | 4 | 0 |
| Dicotyledons | 13 | 9 | 1 |
| **TOTAL** | **41** | **18** | **1** |

**Table 2.** Abundance of common epiphytes as estimated by the number of host trees (out of 25) occupied by each species.

| **Species** | **Number of host trees occupied** |
|---|---|
| *Nephrolepis tuberosa* | 21 |
| *Collospermum montanum* | 11 |
| *Nephrolepis saligna* | 10 |
| *Peperomia lagiostigma var. lagiostigma* | 8 |
| Hymenophyllaceae | 6 |
| *Peperomia attenuata var. roseispica* | 6 |
| *Lindsaea pickeringii* | 5 |

**Table 3.** List of important, common, and/or unique vascular cloud forest taxa in the Pacific. Plants newly added to an initial list by Merlin and Juvik (1993) are typed in bold.

| FAMILY | GENERA |
|---|---|
| Arecaceae | *Ptychosperma* |
| Chloranthaceae | *Ascarina* |
| Cunnoniaceae | *Weinmannia* |
| Cyatheaceae | *Cyathea* |
| Dicksoniaceae | ***Dicksonia*** |
| Elaeocarpaceae | *Elaeocarpus* |
| Ericaceae | *Vaccinium* |
| **Gesneriaceae** | ***Cyrtandra*** |
| **Hymenophyllaceae** | ***Crepidomanes, Hymenophyllum, Trichomanes*** |
| **Liliaceae** | ***Collospermum*** |
| Melastomataceae | ***Astronidium***, *Medinilla* |
| Myrtaceae | *Metrosideros* |
| **Orchidaceae** | ***Dendrobium* and other genera** |
| Pandanaceae | *Freycinetia* |
| **Peperomiaceae** | ***Peperomia*** |

Probably the most obvious conclusion of this study is the absence of good botanical inventory data and quantitative vegetation data for cloud forests in the tropical insular Southwest Pacific. Considering the threats posed by climate change, baseline surveys of these forests need to be considered a high priority because cloud forests are one of the most vulnerable ecosystems to a global rises in temperatures and associated changes in the location of cloud layers. This is especially true for islands in the Southwest Pacific, which rarely exceed 2,000 m and therefore do not allow for upward migration of this ecosystem (Loope and Giambelluca, 1998; Still *et al*., 1999).

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**Appendix 1: Species checklist for the cloud forest of Mt. Delaco, Gau.** Nomenclature follows Smith (1979-1996) and Brownlie (1977). *= recent introduction, I = indigenous, E=Endemic.

## PTERIDOPHYTA

*LYCOPSIDA*

LYCOPSIDACEAE
*Huperzia trifoliata* (Copel.) J. Holub [E]

*FILICOPSIDA*

CULCITACEAE
*Calochlaena straminea* (Labill.) M.D.Turner & R.A.White [I]

DAVALLIACEAE
*Davallia denticulata* (Burm. f.) Mett. ex. Kuhn var. *elata* (G.Forst.) Mett. ex Kuhn [I]
*Davallia solida* (G.Forst.) Sw. var. *fejeensis* (Hook.) Nootenboom [I (var. E)]
*Nephrolepis saligna* Carr. [E]
*Nephrolepis tuberosa* (Bory ex Willd.) Presl. [I]

DICKSONIACEAE
*Dicksonia brackenridgei* Mett. [E]

HYMENOPHYLLACEAE
*Hymenophyllum affine* Brack. [E]
*Hymenophyllum denticulatum* Sw. [I]
*Hymenophyllum feejensis* Brack. [I]
*Hymenophyllum polyanthos* (Sw.) Sw. [I]
*Crepidomanes endlicherianum* (C.Presl) P.S.Green [I]
*Crepidomanes humile* (G. Forst.) Bosch [I]
*Trichomanes tahitense* Nadeaud [I]

HYPOLEPIDACEAE
*Histiopteris incisa* (Thunb.) J.Sm. [I]

LINDSAEACEAE
*Lindsaea pickeringii* (Brack.) Mett. ex Kuhn [I]

MARATTIACEAE
*Marattia smithii* Mett. ex Kuhn [I]

OSMUNDACEAE

*Leptopteris wilkesiana* (Brackenr.) C. Christ. [I]

**MAGNOLIOPHYTA**

*MONOCOTYLEDONES*

ARACEAE
*Epipremnum pinnatum* (L.) Engl. [I]

CYPERACEAE
*Carex dietrichiae* Boeck. [I]

FLAGELLARIACEAE
*Flagellaria indica* L. [E]

LILIACEAE
*Collospermum montanum* (Seem.) Skottsb. [E]

ORCHIDACEAE
*Dendrobium mohlianum* Reichenb. f. [I]
*Dendrobium tokai* Reichenb. f. [I]
*Eria bulbophylloides* C.Schweinf. [E]
*Malaxis lunata* (Schlechter) Ames [I]

PANDANACEAE
*Freycinetia* sp. [I]

ZINGIBERACEAE
*Alpinia boia* Seem. [E]

*DICOTYLEDONES*

AQUIFOLIACEAE
*Ilex vitiensis* A.Gray [E]

ASCLEPIADACEAE
*Hoya megalantha* Turrill [E]

CHLORANTHACEAE
*Ascarina diffusa* A.C.Sm. [I]

GESNERIACEAE
*Cyrtandra victoriae* Gillesp. [E]

LAURACEAE
*Litsea vitiana* (Meisn.) Benth. & Hook. [E]

MELASTOMATACEAE
*Astonidium* sp. [E]
**Clidemia hirta* (L.) D.Don

MONIMIACEAE
*Hedycarya dorstenoides* A.Gray. [I]

MYRSINACEAE
*Rapanea myricifolia* (A.Gray) Mez [I]

MYRTACEAE
*Syzygium eugenioides* (Merr. & L.M.Perry) Biffin & Craven [E]
*Metrosideros collina* (J.R. & G.Forst.) A.Gray [I]

PEPEROMIACEAE
*Peperomia lasiostigma* C.DC. var. *lasiostigma* [E]
*Peperomia attenuata* Yuncker var. *roseispica* [E]

RUBIACEAE
*Psychotria parvula* A.Gray [E]

**Appendix 2:Height, dbh and epiphyte cover for the different individuals within the 40m transect.**

| **Species** | **Height (m)** | **dbh (cm)** | **Epiphyte Cover** |
|---|---|---|---|
| *Rapanea myricifolia* | 3.5 | 6.9 | 3 |
| *Rapanea myricifolia* | 4.0 | 9.7 | 4 |
| *Dicksonia brackenridgei* | 2.0 | 13.0 | 5 |
| *Rapanea myricifolia* | 3.0 | 15.0 | 3 |
| *Dicksonia brackenridgei* | 2.0 | 14.0 | 5 |
| *Dicksonia brackenridgei* | 3.5 | 13.0 | 5 |
| *Hedycarya dorstenoides* | 6.0 | 15.5 | 5 |
| *Dicksonia brackenridgei* | 2.0 | 13.7 | 5 |
| *Litsea vitiana* | 5.0 | 14.0 | 5 |
| *Dicksonia brackenridgei* | 2.0 | 12.0 | 5 |
| *Hedycarya dorstenoides* | 6.0 | 20.0 | 5 |
| *Dicksonia brackenridgei* | 2.5 | 13.3 | 5 |
| *Dicksonia brackenridgei* | 3.0 | 31.6 | 5 |
| *Astronidium confertiflorum* | 3.0 | 7.7 | 5 |
| *Ascarina diffusa* | 5.0 | 13.9 | 4 |
| *Ascarina diffusa* | 5.0 | 13.3 | 5 |
| *Astronidium confertiflorum* | 5.0 | 7.0 | 3 |
| *Dicksonia brackenridgei* | 3.0 | 14.6 | 4 |
| *Dicksonia brackenridgei* | 4.0 | 19.5 | 5 |
| *Alpinia boia* | 7.0 | 8.0 | 1 |
| *Dicksonia brackenridgei* | 3.0 | 11.0 | 3 |
| *Alpinia boia* | 7.0 | 6.9 | 1 |
| *Dicksonia brackenridgei* | 4.0 | 12.6 | 3 |
| *Syzygium eugenoides* | 5.0 | 12.7 | 5 |
| *Ilex vitiensis* | 6.0 | 17.9 | 5 |