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Height-diameter relationships of tropical Atlantic moist forest trees in southeastern Brazil

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ABSTRACT: Site-specific height-diameter models may be used to improve biomass estimates for forest inventories where only diameter at breast height (DBH) measurements are available. In this study, we fit height-diameter models for vegetation types of a tropical Atlantic forest using field measurements of height across plots along an altitudinal gradient. To fit height-diameter models, we sampled trees by DBH class and measured tree height within 13 one-hectare permanent plots established at four altitude classes. To select the best model we tested the performance of 11 height-diameter models using the Akaike Information Criterion (AIC). The Weibull and Chapman-Richards height-diameter models performed better than other models, and regional site-specific models performed better than the general model. In addition, there is a slight variation of height-diameter relationships across the altitudinal gradient and an extensive difference in the stature between the Atlantic and Amazon forests. The results showed the effect of altitude on tree height estimates and emphasize the need for altitude-specific models that produce more accurate results than a general model that encompasses all altitudes. To improve biomass estimation, the development of regional height-diameter models that estimate tree height using a subset of randomly sampled trees presents an approach to supplement surveys where only diameter has been measured.

Keywords: tree height, elevation

Introduction

The Brazilian Atlantic Forest (hereafter referred to as Atlantic Forest) is a biodiversity hotspot considered as one of the global centers of tree diversity and endemism (Guedes-Bruni et al., 2009) and one of the most threatened tropical forest regions in the world (Myers et al., 2000). Although the Atlantic Forest is one of the most diverse biomes on Earth there is limited information regarding the structure and biomass of this forest (Alves et al., 2010; Vieira et al., 2008).

Tree biomass stocks of tropical forests are traditionally estimated using forest inventory data from sample plots (Brown, 1997) and allometric models that relate tree dry mass to easily measurable variables such as diameter at breast height (DBH) and total height (Chave et al., 2005). These variables, along with wood density (Baker et al., 2004), are applied in general allometric models (Chave et al., 2005) when site-specific models are not available. As there are no available allometric models developed destructively for old-growth Atlantic forest sites (Alves et al., 2010; Vieira et al., 2008), a pantropical allometric model developed by Chave et al. (2005) for tropical moist forests has been suggested to estimate the live tree aboveground biomass (AGB) for the coastal tropical Atlantic forest using DBH, wood density and total height (Alves et al., 2010).

Although useful, the measurement of tree height in tropical forest inventories is time-consuming and expensive. As a consequence, there are few forest models that use tree height as an independent variable (Fang and Bailey, 1998). An alternative to height measurement for all individuals is the application of site-specific height-diameter models that relate DBH with measured tree height (Batista et al., 2001). However, height-diameter relationships vary within a geographic region (Peng et al., 2001) due to species composition and local environmental conditions. Hence, there is a growing consensus that the use of site specific height-diameter models fitted using field measures of tree height is an important alternative to reduce uncertainties in forest biomass estimation in tropical forests (Chave et al., 2005; Feldpausch et al., 2010; Nogueira et. al., 2008) and to study forest structure. Therefore, the main objective of this study is to fit and investigate the relation between DBH and tree height across sites located at different altitudes in the Atlantic Forest of the southeast region of Brazil.

Materials and Methods

This study was carried out in the São Paulo State Park of *Serra do Mar* (PESM), southeast Brazil, and nearby the Picinguaba and Santa Virginia stations (44°48′ W, 23° 22′ S). The state park contains 47,500 ha of diverse tropical ecosystems, including mangroves, *restinga* (sandy coastal plain forests), and humid tropical forests from

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sea level up to 1,200 m a.s.l. (SMA, 1998). According to Veloso et al. (1991), the Atlantic Forest, at the latitude of this study, can be subdivided into vegetation types by altitude as follows: lowland forest, submontane forest and montane forest. Along the coastline, there is another Atlantic forest type known as *restinga* or coastal seasonally flooded forest (Araújo, 1992). Mean annual rainfall in the study area is c. 2600 mm, and monthly average temperature ranges from 17.6 °C to 24.7 °C (Sentelhas et al., 1999) varying according to altitude.

From 2006 until 2007, 13 one-hectare permanent plots were established along an altitudinal transect at the *Serra do Mar* state park to evaluate forest diversity and ecosystem function variation within the north coastal Atlantic Forest of São Paulo state (Alves et al., 2010; Joly et al., 2008). Aiming to represent the range of local environmental conditions, four one-hectare permanent plots (100 × 100 m) were established at varying altitudes: in the lowland forest at 100 m altitude, in the submontane forest at 400 m altitude and in the montane forest at 1,000 m altitude. Due to its limited representativeness within the Park relative to the other forest types, only one plot was established at sea level in the *restinga* forest. All trees ≥ 4.8 cm DBH were tagged and mapped to a horizontal distance of ± 10 cm in each permanent plot, and tree circumference was measured within ± 1 mm (Alves et al., 2010). Soils in lowland, submontane and montane forest sites are classified as Inceptisol (USDA taxonomy) with more than 50 % of sand content and in the *restinga* forest the soil is classified as Quartzipsamment (USDA taxonomy) with more than 80 % of sand content (Alves et al., 2010). These soils have in common a high sand content, with low pH, low phosphorus concentration, low sum of bases and high aluminum saturation. The density of trees, palms and tree ferns with DBH ≥ 4.8 cm ranged from 1467 up to 1885 stems ha^{-1} (average of 1,626 stems ha^{-1}) in the *restinga* forest, 1,170 up to 1,298 stems ha^{-1} (average of 1,230 stems ha^{-1}) in the lowland forest, 1,517 up to 1,926 stems ha^{-1} (average of 1,727 stems ha^{-1}) in the submontane forest and 1,454 up to 1,834 stems ha^{-1} (average of 1,723 stems ha^{-1}) in the montane forest (Alves et al., 2010). The most rich families in these forests sites are: Myrtaceae, Rubiaceae, Fabaceae, and Lauraceae

Common canopy tree species with DBH ≥ 30 cm include: *Hieronyma alchorneoides* Allemão, *Virola bicuhyba* (Schott ex Spreng.) Warb, *Eriotheca pentaphylla* (Vell.) A. Robyns, *Sloanea guianensis* (Aubl.) Benth, *Cryptocaria mandiocanna* Meisn., *Ecclinusa ramiflora* Mart., *Licania hoehnei* Pilg. and *Chrysophyllum viride* Mart. & Eichler ex Miq. For a full description of the sampling design and stand site characteristics, see Alves et al. (2010) and Sousa Neto et al. (2010). Hereafter we will refer to these forest types by the altitudes of occurrence.

Using the database generated by Alves et al. (2010), we randomly selected 268 trees stratified by altitude of occurrence and by DBH class to perform tree height measurements. The DBH classes were: < 10 cm, 10–30 cm, 30–50 cm and ≥ 50 cm. We did not include palms in our analysis. Approximately the same number of randomly selected individuals was measured for each diameter class.

Tree height was set as the vertical distance measured from ground to the topmost live leaf. A telescoping measuring rod (Crain Enterprise, model no. 90182) was used to measure the height of trees up to 16 m height. For trees taller than 16 m we used a handheld laser range finder (Impulse-200LR, Laser Technology Inc., Englewood, Colorado) that measures distance and calculates height using an angular measurement from a clinometer integrated into the instrument.

There are numerous studies that relate height and diameter for different species and forest regions. In tropical forests, there are few studies reporting height-diameter models and limited information about their performance (Batista et al., 2001; Fang and Bailey, 1998; Feldpausch et al., 2010). Here, we propose a performance test of the eleven linear and non-linear height-diameter models (Table 1), tested earlier by Fang and Bailey (1998) and Batista et al. (2001) in other tropical forests.

The non-linear and linear models were fitted using the functions "Nonlinear Least Squares" and "Fitting linear models" of the R statistical software packages (R Development Core Team, 2011). To assess the performance of height-diameter models and then to test the effect of altitude on estimates, we applied the Akaike Information Criterion (AIC) (Burnham and Anderson, 2002; Chave et

Table 1 – Height-diameter models selected for performance test with data from tropical Atlantic Forest of the São Paulo State Park of Serra do Mar, southeastern Brazil.

Models	Reference
Linear models	
(1) $H = a + bD$	Batista et al. (2001); Vanclay (1995)
(2) $H = a + b\ln D$	Curtis (1967); Fang and Bailey (1998)
Nonlinear models	
Hyperbolic models	
(3) $H = aD/(b + D)$	Fang and Bailey (1998); Tang (1994)
(4) $H = D^2/(a + bD)^2$	Fang and Bailey (1998); Huang and Titus (1992)
Power model	
(5) $H = aD^b$	Batista et al. (2001); Fang and Bailey (1998)
Exponential model	
(6) $H = e^{a + b/(D+1)}$	Fang and Bailey (1998); Huang and Titus (1992)
Chapman-Richards	
(7) $H = a(1 - e^{-bD})^c$	Batista et al. (2001); Huang and Titus (1992)
Weibull	
(8) $H = a(1-\exp[-bD^c])$	Batista et al. (2001); Bailey (1979)
Monomolecular	
(9) $H = a(1 - b\,e^{-c\,D})$	Batista et al. (2001); Fang and Bailey (1998)
Gompertz	
(10) $H = a\exp^{(-b\exp[-cD])}$	Batista et al. (2001); Huang and Titus (1992)
Logistic	
(11) $H = a/(1 + be^{-cD})$	Batista et al. (2001); Huang and Titus (1992)

Note: H = total tree height (m); D = DBH (cm); *a*, *b* and *c* are parameters to be estimated; *e* = the base of natural logarithm al., 2005). The formula of AIC used as the criterion for model selection (Chave et al., 2005) is:

$$AIC = -2\ Log(L) + 2p$$

where L is the likelihood of the fitted model and p is the total number of parameters in the model. The best model of the eleven tested models of this database will minimize the AIC value (Burnham and Anderson, 2002). Our analysis was structured as follows: (i) first, we pooled the data (using the subset of 268 trees with measured heights) to select the best model as described above; (ii) second, using the best overall model(s) we fitted the best site-specific height diameter model and calculated the AIC value for each altitude; (iii) finally, we compared the pooled AIC value with the AIC from the sum of the site-specific height-diameter models to test the altitudinal effect (because the data came from the same source; see Burnham and Anderson, 2002). This sum matches the performance of the selected height-diameter model taking into account the site-specific altitude effect, and so can be compared with the pooled model AIC value (Burnham and Anderson, 2002). If the pooled model has a smaller AIC value, there is no altitudinal effect on tree height estimates. The maximum tolerance used to select the best models using the AIC value was equal to Log8 or 2 (Burnham and Anderson, 2002). Although our data apparently show some degree of heteroscedasticity (Figure 1), we decided to acknowledge it and then proceed with our model selection and tests since AIC is not sensitive to the heteroscedasticity (Burnham and Anderson, 2002).

Results and Discussion

For the pooled data set the non-linear Weibull and Chapman-Richards models performed best (Table 2). All parameters of the best fit models were significant ($p \leq 0.01$), with the exception of the *b* parameter of the Chapman-Richards model in the 100 m and 400 m forests (Table 3). Consequently, we will analyze the height-diameter relationships variation using only the Weibull height estimates. The height-diameter fits are shown in Figure 1 separated by site/altitude.

Non-linear height-diameter models have biological interpretations and are less sensitive to individual points, making them more stable and more reliable for data extrapolation (Batista et al., 2001). Batista et al. (2001) and Fang and Bailey (1998) also found better performance of non-linear height-diameter models in other tropical forests. The Weibull model has been widely used to describe tree allometric relationships,

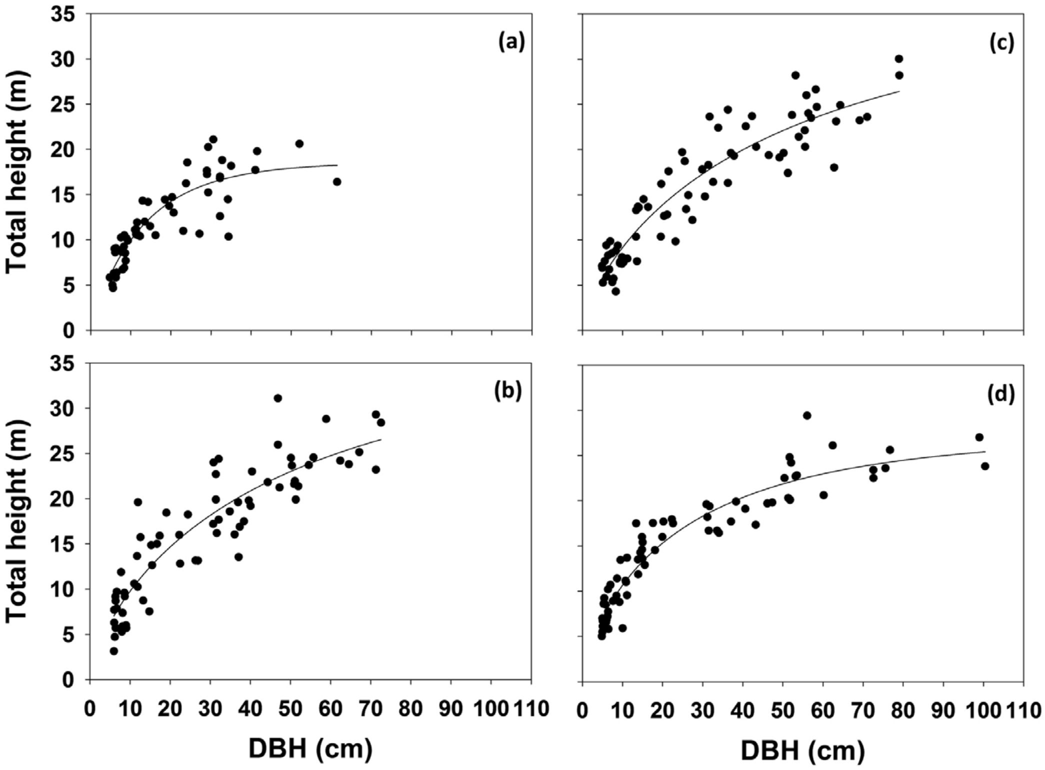

Figure 1 – Weibull fit of tree height-diameter relationships for forests located at sea level (a), 100 m (b), 400 m (c) and 1,000 m asl (d). Total height: tree height measured by laser or telescopic rod. Data are from the Atlantic Forest of the São Paulo State Park of Serra do Mar, southeastern Brazil. DBH = diameter at breast height.

especially for modeling height-diameter relationships (Batista et al., 2001; Fang and Bailey, 1998; Muller-Landau et al., 2006).

The site specific height-diameter Weibull and Chapman-Richards models (AIC from pooled model with the altitude effect in the Table 3) had better performance than the pooled model fit using the full database (AIC from pooled model without the altitude effect in the Table 2). The latter model had the highest AIC value (Table 2 and Table 3), indicating the effect of altitude on tree height estimates and demonstrating the difficulty of extrapolation using a single height-diameter model along the altitudinal gradient. The same result was found by Tasissa et al. (1997) and (Trincado et al., 2007) probably because the use of site-specific equations accounts for local geographic effects in growth patterns of tree communities. This could be especially true along our altitudinal gradient, where slopes are steeper at 400 m and 1,000 m than at sea level or at 100 m altitude (Alves et al., 2010).

The height-diameter relationship was marginally different among forest types up to a DBH of approximately 30 cm (Figure 2). Above this DBH the relationship for the sea level forest was distinct from the other forests. For a given DBH greater than 30 cm, trees at the sea level are shorter than trees at higher altitudes (Figure 2). However, for a constant DBH of 100 cm, tree

Table 2 – The Akaike Information Criterion (AIC) values for height-diameter models encompassing all altitudes (pooled model). The best model between the 11 tested models minimizes the AIC value. Data are from the Atlantic Forest of the São Paulo State Park of Serra do Mar, southeastern Brazil. See the corresponding model equation in Table 1.

Model	AIC
Weibull	1283.2
Chapman-Richards	1283.5
Monomolecular	1286.7
Hyperbolic model 3	1286.9
Logarithm model	1287.2
Power model	1294.0
Gompertz	1295.0
Logistic	1303.9
Hyperbolic model 4	1305.9
Exponential model	1323.2
Linear model	1368.4

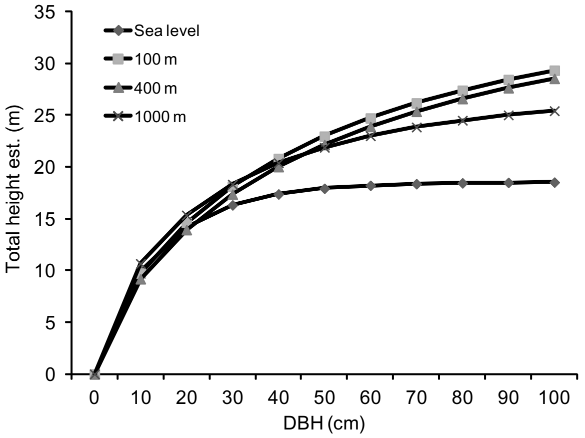

Figure 2 – Tree height estimated by height-diameter Weibull model for forests located at sea level, 100 m, 400 m and 1,000 m asl. Data are from the Atlantic Forest of the São Paulo State Park of Serra do Mar, southeastern Brazil. DBH = diameter at breast height.

Table 3 – Maximum diameter at breast height (DBH) and range of total height measured, parameter values of best fit models and Akaike Information Criterion (AIC) values at sea level, 100 m, 400 m, 1,000 m and all forest types (sum of the site specific AIC values). The data are from the Atlantic Forest of the São Paulo State Park of Serra do Mar, southeastern Brazil.

Weibull model										
				Coefficient						
Altitude	N	DBH max.	H range	Symbol						AIC
				a	S.E.	b	S.E.	c	S.E.	
		cm	m							
Sea level	57	61.4	4.7-21.8	18.540***	1.728	0.093***	0.026	0.919***	0.165	253.1
100 m	70	72.6	3.2-31.1	36.171**	13.418	0.059***	0.012	0.725***	0.147	356.6
400 m	72	78.9	4.3-30.0	35.528**	10.902	0.055***	0.009	0.735***	0.123	354.7
1,000 m	69	100.4	5.2-29.4	27.188***	2.837	0.091***	0.013	0.738***	0.093	295.3
All forest types	268	100.4	3.2-31.1	32.304***	4.054	0.072***	0.005	0.706***	0.059	1259.7
Chapman-Richards model										
				Coefficient						
Altitude	N	DBH max.	H range	Symbol						AIC
				a	S.E.	b	S.E.	c	S.E.	
		cm	m							
Sea level	57	61.4	4.7-21.8	18.413***	1.450	0.069*	0.028	0.878***	0.247	253.2
100 m	70	72.6	3.2-31.1	33.250***	8.476	0.017	0.013	0.662***	0.137	356.7
400 m	72	78.9	4.3-30.0	32.336***	6.574	0.017	0.010	0.682***	0.117	354.8
1,000 m	69	100.4	5.2-29.4	25.759***	1.531	0.031***	0.009	0.649***	0.086	296.1
All forest types	268	100.4	3.2-31.1	29.981***	2.578	0.019***	0.006	0.633***	0.055	1260.8

Note: S. E. is the standard error of the coefficient; $***p < 0.001$; $**p < 0.01$; N, the number of tree samples heights decrease with increasing altitude (Figure 2) if the sea level forest is excluded.

At sea level, trees are seasonally flooded during heavy rain events and particularly during the wet season when the soil remains flooded for several weeks (Scarano, 2002). Additionally, soils at the sea level have the highest sand content and the lowest nutrient content among all soils along the altitudinal gradient (Sousa Neto et al., 2011). Possibly, these stress factors contribute to the small stature of trees established in this forest type. With exception to the sea level, large DBH tree heights tend to decline with increasing altitudes (Figure 2). The same trend was found by Lieberman et al. (1996), studying an altitudinal gradient in North of Barva Vulcan, Costa Rica.

What are the possible causes for this variation in height-diameter relationships along the altitudinal gradient? Soils at 100 m, 400 m and 1,000 m are Inceptisols, with no significant depth difference along the altitudinal gradient (Alves et al., 2010), and with low nutrient content. They are less sandy and have higher nutrient content than soils at sea level (Sousa Neto et al., 2010). More important, there are no differences in soil depth along the altitudinal gradient (Sousa Neto et al., 2010). However, at higher altitudes, air and soil temperatures are lower, with a high incidence of low level clouds and fog formation that reduces annual irradiance (Sousa Neto et al., 2010). These conditions and strong winds are commonly cited as environmental characteristics that distinguish montane from lowland tropical rain forests (Grubb, 1977; Tanner, 1980) and could be the cause of lower tree heights at higher altitudes. Frequently, strong winds cause decrease of tree stature in tropical forests at high altitude (Lawton, 1982). Exposed trees that grow under stress caused by strong winds tend to grow more in diameter than in height, increasing stem strength (Lawton 1982, 1984).

As well as the difference in slope of the terrain is a plausible cause, the local topographic variation among forest types in this altitudinal gradient (see Alves et al., 2010) might be a factor controlling light availability and ultimately, tree height. Montane and submontane forest are located in steeper terrains when compared to the other forest types, so that the vertical distribution of light is expected to be more asymmetric than in flat areas (Alves et al., 2010). As the trees have the crown exposed to more light, they are shorter, reach larger diameters and have also larger crowns (Alves and Santos, 2002).

While we are not able to pinpoint which of these climate conditions is the cause for the observed altitudinal gradient in tree heights we speculate that all of these conditions as well as the difference in the slope of the terrain are plausible causes.

Finally, the tallest statured forest (100 m altitude) was compared with height-diameter models from other studies within the tropical Amazon forest and showed extensive differences in tree stature among these forests (Figure 3). For trees of or above 20 cm DBH, the tropical Atlantic forest had smaller stature than Amazonian forests in Brazil (Asner et al., 2002; Nogueira et al., 2008). For trees with 100 cm DBH, this difference reached 76 % when compared with trees in central Amazon. This result supports the need to use tree height as an independent variable in biomass allometric models used to compare different tropical forests, especially in sites where regional site specific biomass models are not available (Chave et al., 2005; Feldpausch et al., 2010; Nogueira et al., 2008). This is especially important in the case of the coastal Atlantic forest of southeastern Brazil due to various limitations resulting in vegetation suppression. Therefore, an alternative solution to the development of biomass allometric equations based on destructive measurements (harvested trees) is the application of general pantropical models including height to estimate live above ground biomass (Vieira et al., 2008).

Conclusions

The effect of altitude on tree height estimates was evident and emphasize the need for altitude-specific models that produce more accurate results than a general model that encompasses all altitudes. Tree height has a strong influence on the estimate of live aboveground biomass made by allometric models. To improve biomass estimation, the development of regional height-diameter models that estimate tree height using a subset of randomly sampled trees presents an approach to supplement surveys where only diameters have been measured.

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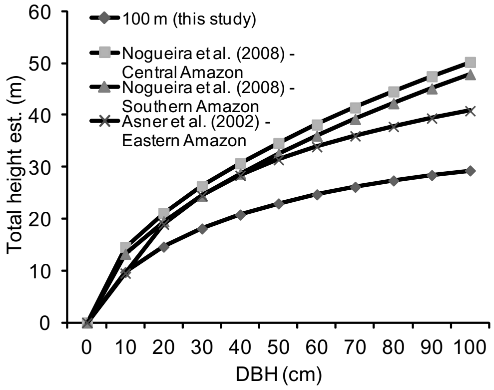

Figure 3 – Tree height estimated by height-diameter Weibull models for a lowland forest at 100 m asl (this study) and for Central, Southern and Eastern Amazon forest. DBH = diameter at breast height.

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Appendix 1 – List of trees stems and species measured along the altitudinal gradient of this study. DBH = diameter at breast height.

Forest	Altitude m	Field code	HT est	DBH	Family	Genus	Species
Sea level	10	A1282	3.5	5.6	Indetermined	-	-
Sea level	10	A0029	14.0	32.2	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A0175	7.0	8.4	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A1099	14.0	23.8	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A1153	17.0	13.5	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A1178	19.0	29.0	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A1330	13.0	23.1	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A1422	12.0	32.3	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A1620	12.0	20.7	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Sea level	10	A0913	18.0	76.9	*Fabaceae*	*Balisia*	*pedicellaris*
Sea level	10	A0460	15.0	52.0	*Clusiaceae*	*Calophyllum*	*brasiliensis*
Sea level	10	A0622	18.0	56.1	*Clusiaceae*	*Calophyllum*	*brasiliensis*
Sea level	10	A1382	16.0	35.0	*Urticaceae*	*Coussapoa*	*microcarpa*
Sea level	10	A0806	4.0	5.8	*Myrtaceae*	*Eugenia*	*riedeliana*
Sea level	10	A1015	4.0	4.8	*Myrtaceae*	*Eugenia*	*neolanceolata*
Sea level	10	A1203	5.0	8.0	*Myrtaceae*	*Eugenia*	*riedeliana*
Sea level	10	A1689	15.0	34.2	*Proteaceae*	*Euplassa*	*cantareirae*
Sea level	10	A0314	9.0	32.2	*Myrtaceae*	*Gomidesia*	*schaueriana*
Sea level	10	A0874	7.0	16.2	*Myrtaceae*	*Gomidesia*	*schaueriana*
Sea level	10	A1004	13.0	61.4	*Myrtaceae*	*Gomidesia*	*schaueriana*
Sea level	10	A1077	17.0	22.9	*Nyctaginaceae*	*Guapira*	*opposita*
Sea level	10	A1173	14.0	12.3	*Annonaceae*	*Guatteria*	*gomeziana*
Sea level	10	A1277	8.0	11.0	*Annonaceae*	*Guatteria*	*gomeziana*
Sea level	10	A1247	11.0	41.1	*Aquifoliaceae*	*Ilex*	*integerrima*
Sea level	10	A0569	12.0	29.3	*Fabaceae*	*Inga*	*subnuda*
Sea level	10	A0234	4.0	5.9	*Bignoniaceae*	*Jacaranda*	*puberula*
Sea level	10	A0744	6.0	11.3	*Bignoniaceae*	*Jacaranda*	*puberula*
Sea level	10	A0897	11.0	27.1	*Bignoniaceae*	*Jacaranda*	*puberula*
Sea level	10	A1171	14.0	34.4	*Bignoniaceae*	*Jacaranda*	*puberula*
Sea level	10	A1199	12.0	8.7	*Bignoniaceae*	*Jacaranda*	*puberula*
Sea level	10	A1520	9.0	18.5	*Bignoniaceae*	*Jacaranda*	*puberula*
Sea level	10	A1602	12.0	32.8	*Bignoniaceae*	*Jacaranda*	*puberula*
Sea level	10	A0312	5.0	8.9	*Clusiaceae*	*Kielmeyera*	*petiolaris*
Sea level	10	A0852	8.0	6.2	*Myrtaceae*	*Marlierea*	*tomentosa*
Sea level	10	A1046	8.0	11.3	*Myrtaceae*	*Marlierea*	*obscura*
Sea level	10	A1596	6.0	6.1	*Myrtaceae*	*Marlierea*	*tomentosa*
Sea level	10	A0269	6.0	8.3	*Celastraceae*	*Maytenus*	*litoralis*
Sea level	10	A0784	4.0	6.5	*Celastraceae*	*Maytenus*	*litoralis*
Sea level	10	A1176	6.0	6.3	*Celastraceae*	*Maytenus*	*litoralis*
Sea level	10	A1519	7.0	7.6	*Celastraceae*	*Maytenus*	*litoralis*
Sea level	10	A0183	3.0	7.6	*Melastomataceae*	*Miconia*	*dodecandra*
Sea level	10	A0095	10.0	11.6	*Myrtaceae*	*Myrcia*	*acuminatissima*
Sea level	10	A0870	10.0	11.8	*Myrtaceae*	*Myrcia*	*acuminatissima*
Sea level	10	A0887	9.0	8.3	*Myrtaceae*	*Myrcia*	*acuminatissima*
Sea level	10	A1144	10.0	8.6	*Myrtaceae*	*Myrcia*	*multiflora*
Sea level	10	A1167	7.0	6.0	*Myrtaceae*	*Myrcia*	*acuminatissima*

Continue...

Appendix 1 – Continuation.

Sea level	10	A1168	13.0	14.8	*Myrtaceae*	*Myrcia*	*acuminatissima*
Sea level	10	A1368	10.0	9.3	*Myrtaceae*	*Myrcia*	*acuminatissima*
Sea level	10	A0917	8.0	6.3	*Lauraceae*	*Nectandra*	*oppositifolia*
Sea level	10	A1427	11.0	30.6	*Lauraceae*	*Nectandra*	*oppositifolia*
Sea level	10	A1635	12.0	24.1	*Lauraceae*	*Nectandra*	*oppositifolia*
Sea level	10	A0529	17.0	29.0	*Fabaceae*	*Ormosia*	*arborea*
Sea level	10	A0226	8.0	19.6	*Euphorbiaceae*	*Pera*	*glabrata*
Sea level	10	A0259	8.0	14.3	*Euphorbiaceae*	*Pera*	*glabrata*
Sea level	10	A0493	10.0	13.0	*Euphorbiaceae*	*Pera*	*glabrata*
Sea level	10	A0536	9.0	20.3	*Euphorbiaceae*	*Pera*	*glabrata*
Sea level	10	A0562	6.0	11.3	*Euphorbiaceae*	*Pera*	*glabrata*
Sea level	10	A0004	12.0	41.5	*Fabaceae*	*Sclerolobium*	*denudatum*
Sea level	10	A0825	5.0	5.4	*Fabaceae*	*Swartzia*	*simplex var. grandiflora*
Sea level	10	A0465	12.0	32.2	*Anacardiaceae*	*Tapirira*	*guianensis*
Sea level	10	A0955	17.0	29.3	*Anacardiaceae*	*Tapirira*	*guianensis*
Lowland	100	C0056	22.0	72.6	Indetermined	-	-
Lowland	100	C0135	18.0	58.9	Indetermined	-	-
Lowland	100	C0263	15.0	36.9	Indetermined	-	-
Lowland	100	C0292	21.0	40.0	Indetermined	-	-
Lowland	100	C0345	18.0	64.6	Indetermined	-	-
Lowland	100	C0350	8.0	6.7	Indetermined	-	-
Lowland	100	C0403	13.0	12.6	Indetermined	-	-
Lowland	100	C0512	20.0	44.3	Indetermined	-	-
Lowland	100	C0590	16.0	32.1	Indetermined	-	-
Lowland	100	D0885	16.0	31.6	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Lowland	100	E0476	7.0	6.4	*Euphorbiaceae*	*Alchornea*	*triplinervia*
Lowland	100	B0765	5.0	6.0	*Rubiaceae*	*Alseis*	*floribunda*
Lowland	100	E0874	6.0	6.7	*Myrsinaceae*	*Ardisia*	*martiana*
Lowland	100	C0697	7.0	8.6	*Rubiaceae*	*Bathysa*	*mendoncaei*
Lowland	100	E0422	4.0	14.8	*Rubiaceae*	*Bathysa*	*mendoncaei*
Lowland	100	E0840	6.0	13.3	*Rubiaceae*	*Bathysa*	*mendoncaei*
Lowland	100	B0168	12.0	39.6	*Meliaceae*	*Cabralea*	*canjerana*
Lowland	100	D0929	16.0	38.4	*Myrtaceae*	*Calyptranthes*	*lucida*
Lowland	100	B0414	13.0	15.5	*Sapotaceae*	*Chrysophyllum*	*flexuosum*
Lowland	100	D0798	6.0	11.9	*Sapotaceae*	*Chrysophyllum*	*flexuosum*
Lowland	100	C0848	8.0	7.8	*Chrysobalanaceae*	*Couepia*	*venosa*
Lowland	100	B0798	5.0	6.4	*Rubiaceae*	*Coussarea*	*meridionalis var. porophylla*
Lowland	100	E0114	6.5	9.1	*Rubiaceae*	*Coussarea*	*accedens*
Lowland	100	B0241	21.0	67.1	*Sapindaceae*	*Cupania*	*oblongifolia*
Lowland	100	C0841	13.0	31.4	*Sapindaceae*	*Cupania*	*oblongifolia*
Lowland	100	C0703	18.0	30.8	*Malvaceae*	*Eriotheca*	*pentaphylla*
Lowland	100	D0052	18.0	54.6	*Malvaceae*	*Eriotheca*	*pentaphylla*
Lowland	100	B0349	9.0	22.3	*Myrtaceae*	*Eugenia*	*neoaustralis*
Lowland	100	D0731	5.5	9.0	*Myrtaceae*	*Eugenia*	*cf fusca*
Lowland	100	D0739	6.5	6.0	*Myrtaceae*	*Eugenia*	*oblongata*
Lowland	100	B0790	12.0	46.9	*Moraceae*	*Ficus*	*gomelleira*
Lowland	100	D0925	16.0	46.9	*Moraceae*	*Ficus*	*sp*
Lowland	100	B0754	5.0	8.0	*Nyctaginaceae*	*Guapira*	*nitida*
Lowland	100	E0749	15.0	34.9	*Nyctaginaceae*	*Guapira*	*opposita*
Lowland	100	E1200	11.0	37.1	*Nyctaginaceae*	*Guapira*	*opposita*
Lowland	100	B0020	15.0	62.4	*Phyllanthaceae*	*Hieronyma*	*alchorneoides*
Lowland	100	C0712	12.0	12.0	*Phyllanthaceae*	*Hieronyma*	*alchorneoides*
Lowland	100	E0014	14.0	71.3	*Phyllantaceae*	*Hieronyma*	*alchorneoides*
Lowland	100	E0552	13.0	47.3	*Phyllantaceae*	*Hieronyma*	*alchorneoides*
Lowland	100	D0067	16.0	75.1	*Phyllanthaceae*	*Hyeronima*	*alchorneoides*

Continue...

Appendix 1 – Continuation.

Lowland	100	C0707	9.0	15.3	*Euphorbiaceae*	*Mabea*	*piriri*
Lowland	100	D1057	12.0	19.1	*Euphorbiaceae*	*Mabea*	*piriri*
Lowland	100	B0811	16.0	36.1	*Myrtaceae*	*Marlierea*	*silvatica*
Lowland	100	D0660	8.0	22.5	*Myrtaceae*	*Marlierea*	*cf obscura*
Lowland	100	E1243	16.0	50.9	*Celastraceae*	*Maytenus*	*sp1*
Lowland	100	C1005	18.0	51.9	*Monimiaceae*	*Mollinedia*	*sp*
Lowland	100	D0217	9.0	8.7	*Monimiaceae*	*Mollinedia*	*schottiana*
Lowland	100	D0260	6.0	6.0	*Monimiaceae*	*Mollinedia*	*schottiana*
Lowland	100	D1125	14.0	30.7	*Monimiaceae*	*Mollinedia*	*lamprophylla*
Lowland	100	E0360	7.0	8.1	*Monimiaceae*	*Mollinedia*	*schottiana*
Lowland	100	E0551	6.0	11.0	*Monimiaceae*	*Mollinedia*	*schottiana*
Lowland	100	D0292	5.0	8.1	*Lauraceae*	*Ocotea*	*divaricata*
Lowland	100	E0563	7.0	16.7	*Lauraceae*	*Ocotea*	*velloziana*
Lowland	100	E0686	7.0	11.7	*Lauraceae*	*Ocotea*	*dispersa*
Lowland	100	B0606	14.0	37.3	*Urticaceae*	*Pourouma*	*guianensis*
Lowland	100	B0880	13.0	26.9	*Sapotaceae*	*Pouteria*	*cf. venosa*
Lowland	100	D0258	12.0	33.4	*Sapotaceae*	*Pouteria*	*cf venosa*
Lowland	100	E0527	10.0	35.4	*Sapotaceae*	*Pouteria*	*venosa*
Lowland	100	D0688	12.0	32.1	*Proteaceae*	*Roupala*	*sp*
Lowland	100	E0104	4.0	6.2	*Rubiaceae*	*Rudgea*	*vellerea*
Lowland	100	B0287	12.0	24.4	*Rubiaceae*	*Rustia*	*formosa*
Lowland	100	E0769	15.0	50.1	*Sapotaceae*	*Sapotaceae*	*sp*
Lowland	100	B0461	6.0	17.4	*Myrtaceae*	*sp*	
Lowland	100	C0467	12.0	26.3	*Myrtaceae*	*sp*	
Lowland	100	B1097	8.0	30.6	*Combretaceae*	*Terminalia*	*januaerensis*
Lowland	100	E0141	16.0	71.3	*Combretaceae*	*Terminalia*	*januarensis*
Lowland	100	B0044	7.0	6.4	*Olacaceae*	*Tetrastylidium*	*grandifolium*
Lowland	100	B0472	17.0	31.4	*Euphorbiaceae*	*Tetrorchidium*	*rubrivenium*
Lowland	100	D0768	12.0	50.4	*Meliaceae*	*Trichilia*	*lepdota*
Lowland	100	B1139	16.0	51.1	*Myristicaceae*	*Virola*	*bicuhyba*
Lowland	100	D0305	14.0	55.7	*Myristicaceae*	*Virola*	*bicuhyba*
Lowland	100	E0689	15.0	40.4	*Myristicaceae*	*Virola*	*bicuhyba*
Lowland	100	E0966	14.0	51.3	*Myristicaceae*	*Virola*	*bicuhyba*
Submontane	400	G1541	14.0	55.4	Indetermined	-	-
Submontane	400	G1718	5.8	5.0	Indetermined	-	-
Submontane	400	G0423	5.0	5.1	*Rubiaceae*	*Alseis*	*floribunda*
Submontane	400	H0304	7.0	8.8	*Myrsinaceae*	*Ardisia*	*martiana*
Submontane	400	H0021	10.0	31.9	*Rubiaceae*	*Bathysa*	*australis*
Submontane	400	H1259	8.0	13.4	*Rubiaceae*	*Bathysa*	*mendoncaei*
Submontane	400	J0016	7	7.0	*Rubiaceae*	*Bathysa*	*mendoncaei*
Submontane	400	G0819	14.0	24.9	*Urticaceae*	*Cecropia*	*glaziovii*
Submontane	400	H0615	8.0	13.4	*Sapotaceae*	*Chrysophyllum*	*flexuosum*
Submontane	400	H1368	18.0	49.1	*Chrysobalanaceae*	*Couepia*	*venosa*
Submontane	400	G0899	8.0	8.4	*Rubiaceae*	*Coussarea*	*accedens*
Submontane	400	H0595	9.0	16.4	*Rubiaceae*	*Coussarea*	*accedens*
Submontane	400	H0617	7.0	19.6	*Rubiaceae*	*Coussarea*	*accedens*
Submontane	400	H0731	4	8.3	*Rubiaceae*	*Coussarea*	*meridionalis var. porophyla*
Submontane	400	J0908	6	11.2	*Rubiaceae*	*Coussarea*	*meridionalis var. porophylla*
Submontane	400	G0081	20.0	33.9	*Lauraceae*	*Cryptocarya*	*mandioccana*
Submontane	400	J0902	17	52.3	*Sapotaceae*	*Ecclinusa*	*ramiflora*
Submontane	400	H0184	14.0	56.3	*Malvaceae*	*Eriotheca*	*pentaphylla*
Submontane	400	H0254	16.0	50.2	*Malvaceae*	*Eriotheca*	*pentaphylla*
Submontane	400	H0556	14.0	31.4	*Malvaceae*	*Eriotheca*	*pentaphylla*
Submontane	400	H0992	15.0	55.9	*Malvaceae*	*Eriotheca*	*pentaphylla*
Submontane	400	J1588	20	54.0	*Malvaceae*	*Eriotheca*	*pentaphylla*

Continue...

Appendix 1 – Continuation.

Submontane	400	G0606	10.0	40.5	*Myrtaceae*	*Eugenia*	*oblongata*
Submontane	400	J0897	10	15.2	*Myrtaceae*	*Eugenia*	*melanogyna*
Submontane	400	J1104	15	36.3	*Myrtaceae*	*Eugenia*	*kleinii*
Submontane	400	H0404	13.0	46.5	*Rubiaceae*	*Faramea*	*pachyantha*
Submontane	400	J0044	16	27.4	*Rubiaceae*	*Faramea*	*pachyantha*
Submontane	400	J1348	13	37.8	*Rubiaceae*	*Faramea*	*pachyantha*
Submontane	400	G0327	12.0	34.1	*Nyctaginaceae*	*Guapira*	*opposita*
Submontane	400	G1045	6.0	10.3	*Nyctaginaceae*	*Guapira*	*nitida*
Submontane	400	G1305	14.0	55.5	*Nyctaginaceae*	*Guapira*	*opposita*
Submontane	400	H0553	14.0	29.9	*Nyctaginaceae*	*Guapira*	*opposita*
Submontane	400	H0816	10.0	26.4	*Nyctaginaceae*	*Guapira*	*opposita*
Submontane	400	J1534	15	32.6	*Annonaceae*	*Guatteria*	*sp.3_J*
Submontane	400	H1215	17.0	58.4	*Lecythidaceae*	*Lecythis*	*cf. lanceolata*
Submontane	400	H0814	6.0	6.0	*Chrysobalanaceae*	*Licania*	*hoehnei*
Submontane	400	G0227	9.0	13.9	*Myrtaceae*	*Marlierea*	*tomentosa*
Submontane	400	G0884	12.0	25.9	*Myrtaceae*	*Marlierea*	*tomentosa*
Submontane	400	H1558	10.0	30.6	*Myrtaceae*	*Marlierea*	*racemosa*
Submontane	400	J0675	7	5.6	*Melastomataceae*	*Miconia*	*sp*
Submontane	400	H1200	14.0	19.7	*Sapotaceae*	*Micropholis*	*crassipedicellata*
Submontane	400	H0730	6.0	7.4	*Monimiaceae*	*Mollinedia*	*uleana*
Submontane	400	J0428	7	9.9	*Monimiaceae*	*Mollinedia*	*engleriana*
Submontane	400	H0031	5.5	6.4	*Myrtaceae*	*Myrcia*	*pubipetala*
Submontane	400	G0284	7.0	21.2	*Myrtaceae*	*Myrciaria*	*floribunda*
Submontane	400	G0200	7.0	31.7	*Fabaceae*	*Myrocarpus*	*frondosus*
Submontane	400	G0611	7.0	4.9	*Fabaceae*	*Myrocarpus*	frondosus
Submontane	400	H0756	18.0	40.7	*Myrtaceae*	*Neomitranthes*	glomerata
Submontane	400	G0515	11.0	36.3	*Lauraceae*	*Ocotea*	*dispersa*
Submontane	400	H1516	12.0	20.4	*Lauraceae*	*Ocotea*	*dispersa*
Submontane	400	J0235	10	14.1	*Lauraceae*	*Ocotea*	*venulosa*
Submontane	400	G1576	12.0	43.3	*Sapotaceae*	*Pouteria*	*venosa*
Submontane	400	H1140	9.0	62.8	*Sapotaceae*	*Pouteria*	*psammophila*
Submontane	400	J0722	17	71.0	*Sapotaceae*	*Pouteria*	*psammophila*
Submontane	400	J0654	26	18.9	*Burseraceae*	*Protium*	*kleinii*
Submontane	400	G0881	5.5	7.5	*Rubiaceae*	*Psychotria*	*nuda*
Submontane	400	H0748	11.0	21.5	*Myrsinaceae*	*Rapanea*	*hermogenesii*
Submontane	400	G0710	7.0	6.7	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	G0759	6.0	9.9	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	G0781	6.0	13.6	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	G0799	4.5	6.0	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	H0047	4.0	7.8	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	H0269	6.5	9.4	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	H0602	7.0	31.1	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	H1290	7.0	9.4	*Rubiaceae*	*Rudgea*	*jasminoides*
Submontane	400	H1435	13.0	37.0	*Araliaceae*	*Schefflera*	*angustissima*
Submontane	400	G0194	9.0	69.1	*Elaeocarpaceae*	*Sloanea*	*guianensis*
Submontane	400	G0443	18.0	53.2	*Elaeocarpaceae*	*Sloanea*	*guianensis*
Submontane	400	H1019	15.0	51.2	*Elaeocarpaceae*	*Sloanea*	*guianensis*
Submontane	400	J1843	24	58.2	*Elaeocarpaceae*	*Sloanea*	*guianensis*
Submontane	400	J0411	17	79.0	*Moraceae*	*Sorocea*	*hilarii*
Submontane	400	G0544	14.0	64.3	*Combretaceae*	*Terminalia*	*januarensis*
Submontane	400	G0101	25.0	42.3	*Combretaceae*	*Terminalia*	*januarensis*
Submontane	400	J0456	14	25.5	*Meliaceae*	*Trichilia*	*silvatica*
Submontane	400	G0473	20.0	57.0	*Myristicaceae*	*Virola*	*bicuhyba*
Submontane	400	G0552	7.0	23.2	*Myristicaceae*	*Virola*	*bicuhyba*
Submontane	400	J1326	20	78.9	*Myristicaceae*	*Virola*	*bicuhyba*

Continue...

Appendix 1 – Continuation.

Submontane	400	J1377	13	63.3	*Myristicaceae*	*Virola*	*gardneri*
Montane	1000	K0179	16.0	43.2	*Indetermined*	-	-
Montane	1000	K1263	20.0	72.6	*Indetermined*	-	-
Montane	1000	L0599	9.5	9.5	*Indetermined*	-	-
Montane	1000	L0771	3.5	15.0	*Indetermined*	-	-
Montane	1000	L1025	10.5	14.5	*Indetermined*	-	-
Montane	1000	K1584	8.0	9.3	*Indetermined*	-	-
Montane	1000	K0477	20.0	51.3	*Euphorbiaceae*	*Alchornea*	*sp*
Montane	1000	K0870	16.0	47.3	*Euphorbiaceae*	*Alchornea*	*glandulosa*
Montane	1000	K2014	30.0	62.4	*Meliaceae*	*Cabralea*	*canjerana*
Montane	1000	K0375	22.0	51.7	*Sapotaceae*	*Chrysophyllum*	*sp*
Montane	1000	K0572	20.0	76.7	*Sapotaceae*	*Chrysophyllum*	*sp*
Montane	1000	K0710	22.0	72.5	*Sapotaceae*	*Chrysophyllum*	*sp*
Montane	1000	K1140	5.5	5.0	*Sapotaceae*	*Chrysophyllum*	*viride*
Montane	1000	K1255	15.0	53.2	*Sapotaceae*	*Chrysophyllum*	*viride*
Montane	1000	K1636	9.0	13.9	*Sapotaceae*	*Chrysophyllum*	*sp*
Montane	1000	K1843	24.0	100.4	*Sapotaceae*	*Chrysophyllum*	*sp*
Montane	1000	K1646	20.0	99.0	*Chrysobalanaceae*	*Couepia*	*sp*
Montane	1000	K1272	11.0	52.0	*Lauraceae*	*Cryptocarya*	*sp*
Montane	1000	K0353	13.0	14.9	*Sapindaceae*	*Cupania*	*sp*
Montane	1000	K0512	8.0	6.4	*Proteaceae*	*Euplassa*	*sp*
Montane	1000	K1742	25.0	53.5	*Moraceae*	*Ficus*	*sp*
Montane	1000	K1998	30.0	56.1	*Moraceae*	*Ficus*	*sp*
Montane	1000	K0519	18.0	37.1	*Nyctaginaceae*	*Guapira*	*sp*
Montane	1000	K1627	12.0	18.1	*Nyctaginaceae*	*Guapira*	*sp*
Montane	1000	K1814	9.0	13.9	*Nyctaginaceae*	*Guapira*	*sp*
Montane	1000	K0647	5.5	6.0	*Meliaceae*	*Guarea*	*sp*
Montane	1000	K0290	14.0	20.0	*Chrysobalanaceae*	*Hirtella*	*hebeclada*
Montane	1000	K0292	8.5	11.1	*Chrysobalanaceae*	*Hirtella*	*hebeclada*
Montane	1000	K0110	20.0	34.1	*Chrysobalanaceae*	*Licania*	*hoehnei*
Montane	1000	K0524	17.0	46.1	*Chrysobalanaceae*	*Licania*	*hoehnei*
Montane	1000	K0553	22.0	51.8	*Chrysobalanaceae*	*Licania*	*hoehnei*
Montane	1000	K0217	9.0	10.8	*Monimiaceae*	*Mollinedia*	*sp*
Montane	1000	K1586	6.5	6.3	*Monimiaceae*	*Mollinedia*	*sp*
Montane	1000	K1665	7.0	7.6	*Monimiaceae*	*Mollinedia*	*argyrogyna*
Montane	1000	K1987	6.0	6.5	*Monimiaceae*	*Mollinedia*	*schottiana*
Montane	1000	K0729	9.5	13.3	*Myrtaceae*	*Myrcia*	*crocea*
Montane	1000	K1233	13.0	14.9	*Myrtaceae*	*Myrcia*	*crocea*
Montane	1000	K1256	13.0	31.7	*Araliaceae*	*Schefflera*	*sp*
Montane	1000	K1072	5.0	5.1	*Solanaceae*	*Solanum*	*sp*
Montane	1000	K0080	5.0	5.0	*Lauraceae*	*sp*	
Montane	1000	K0128	24.0	33.6	*Myrtaceae*	*sp*	
Montane	1000	K0199	4.5	5.1	*Annonaceae*	*sp*	
Montane	1000	K0303	18.0	31.5	*Lauraceae*	*sp*	
Montane	1000	K0330	5.0	6.0	*Lauraceae*	*sp*	
Montane	1000	K0452	14.0	11.1	Myrtaceae	*sp*	
Montane	1000	K0504	10.0	51.3	*Lauraceae*	*sp*	
Montane	1000	K0623	16.0	22.6	*Myrtaceae*	*sp*	
Montane	1000	K0631	6.0	10.1	*Rubiaceae*	*sp*	
Montane	1000	K0638	7.0	5.7	*Euphorbiaceae*	*sp*	
Montane	1000	K0674	9.5	10.9	*Solanaceae*	*sp*	
Montane	1000	K0725	14.0	30.9	*Lauraceae*	*sp*	
Montane	1000	K0807	8.0	8.7	*Lauraceae*	*sp*	
Montane	1000	K1083	17.0	50.4	*Myrtaceae*	*sp*	
Montane	1000	K1093	14.0	20.2	*Myrtaceae*	*sp*	

Continue...

Appendix 1 – Continuation.

Montane	1000	K1210	14.0	40.6	*Lauraceae*	*sp*
Montane	1000	K1234	7.0	5.5	*Lauraceae*	sp
Montane	1000	K1393	6.5	5.3	*Lauraceae*	sp
Montane	1000	K1452	13.0	15.6	*Lauraceae*	sp
Montane	1000	K1667	16.0	17.6	*Myrtaceae*	sp
Montane	1000	K1669	28.0	75.6	*Lauraceae*	sp
Montane	1000	K1701	20.0	60.2	*Lauraceae*	sp
Montane	1000	K1787	22.0	38.3	*Lauraceae*	sp
Montane	1000	K1794	7.5	7.0	*Myrtaceae*	sp
Montane	1000	K1795	6.0	4.9	*Myrtaceae*	sp
Montane	1000	K1858	15.0	31.2	Lauraceae	sp
Montane	1000	K1882	15.0	22.3	*Myrtaceae*	sp
Montane	1000	K1958	15.0	13.4	*Myrtaceae*	sp
Montane	1000	K1991	7.0	8.5	*Myrtaceae*	sp
Montane	1000	L1055	6.5	6.4	*Myrtaceae*	sp

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