

**Marine and Tropical Sciences  
Research Facility (MTSRF) Project 2.5ii.2  
'Climate Change: Scaling from  
trees to ecosystems'**

**Final Report on Project Activities, June 2010**

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**Project Investigators:**

|                                                    |                             |     |
|----------------------------------------------------|-----------------------------|-----|
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| Objective (b) – Plant Physiology .....             | Dr Will Edwards .....       | JCU |
| Objective (c) – Fluxes of Carbon and Water .....   | Dr Paul Nelson .....        | JCU |
| Objective (d) – Flowering/fruiting Phenology ..... | Dr Caroline Gross .....     | UNE |
| Objective (e) – Insect Populations .....           | Professor Nigel Stork ..... | UM  |



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## Summary

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This final report provides a summary of the outcomes of [MTSRF Project 2.5ii.2](#) over the course of its four-year tenure. At the outset the aim of the project was to provide a detailed process-based understanding of lowland rainforest performance in concert with climatic measurements. This understanding would then be coupled with future climate scenarios provided by [MTSRF Project 2.5ii.1](#) to allow us to predict possible influences of climate change on the Daintree lowland rainforest over the next century.

### Objective (a) – Atmospheric Fluxes

Flux studies at Cape Tribulation have been running for nine years. Throughout this period a drought event in 2002-2003 enabled the assessment of the influence of water stress on the carbon balance of the forest – the conclusion was that wet season recharge is essential in maintaining photosynthetic productivity. Without at least two metres of rainfall in the wet season full photosynthetic activity cannot be maintained throughout the year.

In 2008 a second flux station was installed at Cow Bay, enabling differences in cloud cover (available radiation) to be assessed. An increase in cloud cover in future wet seasons would see a decrease in forest productivity. In a campaign study trace emissions of volatile organic compounds were detected from the forest. Despite this, there are major aerosol formation events in proximity to the forest. The origin of these formation events has yet to be determined but they are undoubtedly important for ensuring rainfall events. Cyclone damage to the ecosystem influenced forest respiration measurably (increased) over the period 2000-2004. A predicted Mean Annual Temperature increase of 3.6°C for the Daintree (CSIRO Marine and Atmospheric Research) and reduced rainfall in the wet season will place the rainforest in a highly stressed situation by 2080. From climatological measurements the Cape Tribulation site has shown an increase in mean annual temperature of 0.6°C since the commencement of the study.

### Objective (b) – Plant Physiology

Using allometric methods and dendrometer bands the annual increment in Above Ground Biomass (AGB) for the >25cm size class of the forest was tracked from March 2007 to March 2010. Over this period there was a steady increase in biomass in the forest from 186.7t to 195.8t. There were differences between species but due to the restricted sample size in the 1Ha plot these could not be positively identified. Leaf litter fall was analysed using circular statistics and found to behave in a spatially defined manner. Further work is proceeding to identify any relationship with soil nutrient status and stem density. The Leaf Area Index (LAI) for the forest is currently 3.5.

### Objective (c) – Below-ground fluxes of carbon and water

**Part (i) Below-ground fluxes of water:** Despite a growing body of knowledge on the hydrology of tropical rainforests, little is known about temporal and spatial patterns of water uptake. Water uptake is particularly relevant to the response of forests to climate change. The aim of this work was to determine uptake rates and the factors controlling them. During a period of 2 years, soil water content and potential were measured at depths of 0.1, 0.75 and 1.5 m. Water uptake was calculated from the change in soil water content during periods with no rainfall. Water uptake ranged from 0 to 12 mm d<sup>-1</sup> and was closely related to mean soil profile water potential. When the soil was wet, daily uptake often exceeded ET<sub>0</sub>, by up to two times. When the soil was dry uptake was far lower than ET<sub>0</sub>. The temporal pattern of uptake is thus clearly different from that of transpiration; trees accumulate water when there is ample supply and lose it in times of water deficit.

**Part (ii) Below-ground fluxes and transformations of carbon:** Ecosystem carbon fluxes depend to a large extent on soil processes. The aim of this work was to determine fluxes of carbon through the soil. Soil carbon content and fertility were measured by analysing topsoil (0-0.1m) samples from across the site (5 x 5 grid across 1 ha, corresponding with litter collection traps) and samples to 1.5m depth from a pit. Topsoil properties varied considerably across the site and canopy cover was spatially correlated with soil fertility and depth/rockiness, as estimated by apparent electrical conductivity. Soil C has a turnover rate of approximately 5% per year. Carbohydrate was the most abundant component of soil organic matter, but its concentration relative to other components decreased with depth. Carbon cycling through the soil at this site is likely to be sensitive to perturbations in rainfall.

### **Objective (d) – Flowering / fruiting phenology**

The phenology sub-project was commenced mid-way through the life-time of the project. It uses two sites the Canopy Crane site (Cape Tribulation) and the SkyRail transect (near Smithfield) to study changes in flowering/fruiting in response to climatic variability. This is necessarily a long term study and the MTSRF project has only initiated the research. One year of data has been collected at both sites. At the Canopy Crane site presence/absence data is scored visually from the gondola of the crane. At the SkyRail transect a d-SLR camera is used to collect 12MP images continuously along both sides of the gondola carriageway. These images are then processed in the laboratory where species showing an event are identified. Data analysis is proceeding on the large amount of digital data collected from the SkyRail transect (1500 high-resolution images/month). Analysis of data from the Canopy Crane site, the historic data set from the SkyRail transect and the new digital method have indicated that we will be able to track changes in flowering/fruiting phenology in response to climatic variability successfully.

### **Objective (e) – Resource related fluctuations in insect populations**

Leaf litter is the resource that the beetles inhabiting the forest floor are reliant on and the insect sub-project established that while there is large temporal variation in beetle abundance throughout the year it could not be correlated in a simple fashion with any of the microclimate variables measured on site over the four years of the study. Sampling of leaf litter inhabiting beetles commenced in 2006 and concluded in December 2009, producing almost 8,000 beetles.

Fluctuations in the density of leaf litter beetles were tested against fluctuations in climatic parameters for the period January 2006 to December 2009. Time series modelling showed that simple positive linear relationships between beetle density and temperature and relative humidity are unlikely to exist. Instead, the effect of climate in influencing temporal variation in beetle density is likely to be much more complex or weak.

A leaf litter manipulation experiment was completed in February 2009. Analyses reveal that the volume of leaf litter is an important determinant of beetle abundance but that beetle responses are complex. Complexity in climatic relationships and responses to leaf litter manipulations suggest a degree of resilience among insects to cope with climatic variability but this depends on how plant productivity and litter fall dynamics are affected.

## Project Results

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### Background

The future of the lowland rainforest in far northern Queensland (and globally) under future climate change is uncertain (Stork *et al.* 2007). This project set out to understand a small area (1Ha) of representative rainforest in the Daintree region in some detail. Our interest in developing a detailed understanding of the response of the rainforest to climate variability is based on historical evidence that the plant community in the Daintree lowlands has been sclerophyll in the past. It has been suggested (Hopkins *et al.* 1996) that based on a charcoal record the ridge behind the study site at Cape Tribulation was covered in sclerophyll forest up until 1.4 kyr BP, now the same ridge is covered in complex mesophyll vine forest. The system has switched and potentially it may switch back again. We need to understand how close to the edge the rainforest community currently is in terms of temperature and water tolerance. It has been established that the overall vegetation patterns in the Wet Tropics rainforest region is influenced strongly by both Mean Annual Precipitation (MAP) and by Mean Annual Temperature (MAT) (Hilbert 2008). Both of these parameters are going to undergo major changes by the year 2085. We are uncertain of the resilience in the plant community to deal with climatic variability as we have no baseline data to work with. In this project we have commenced the process of understanding the drivers of the lowland forest ecosystem by studying the forest from many angles (biophysical, flora, fauna, hydrology, soils) in concert with microclimate measurements. To be of assistance in forward planning for climate change mitigation the results and conclusions from the project will be presented to the modelling teams of MTSRF researchers Professor S. Williams (JCU Centre for Tropical Biodiversity and Climate Change) and Dr D. Hilbert (CSIRO Sustainable Ecosystems). These groups are active in predicting future species distributions and climate refugia using empirical modelling approaches. Our results will help to develop an understanding of what is actually driving observed changes in community distributions, which will in turn allow for more accurate prediction of future climate change refugia.

## Objective (a) – Atmospheric Fluxes

**Principal Investigator: Dr Michael Liddell, James Cook University**

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### Introduction

There is an extensive literature on the measurement of the fluxes of carbon and water from tropical rainforests (Lewis *et al.* 2009, Hutrya *et al.* 2007). The reason for the substantive activity in this area is the importance of understanding carbon and water fluxes as part of the global carbon cycle and in regional water budgets. In Australia there have been no reported eddy covariance flux studies in the lowland tropical rainforests of North Queensland. This work then addresses this gap and at the same time provides an area averaged view of the ecosystem. The measurement of eddy covariance fluxes is based on micrometeorological theory and while relatively robust during the daylight hours has some inherent problems for quantitative results during the night (Baldocchi 2003) that have still to be successfully resolved. It is nevertheless the method that is now globally used to measure the carbon and water performance of ecosystems through networks such as [OzFlux](#) (Australia) and [Fluxnet](#) (Global). The results from the current study then pertain not only to the MTSRF objectives but they will also contribute to the international effort to study tropical rainforest ecosystems which are critical to the carbon balance of the planet.

### Flux and ancillary measurements

The two study sites are the Australian Canopy Crane Research Facility, near Cape Tribulation (CT) and the Daintree Discovery Tower site (DT), near Cow Bay. The forest in both cases is complex mesophyll vine forest (Tracey and Webb 1975). An eddy covariance (EC) flux station was established in 2001 (CT) on the crane tower at 45m and this system has been in continuous operation since then as part of the OzFlux network. In addition to the radiation and climate sensors required for the EC system a separate ground based Automatic Weather Station (AWS) was installed in October 2005, and replaced in March 2010. Over the course of the project the EC system ran reliably with three months' data loss due to problems with the CSAT-3 in 2006 and 2010. A further 12 months' data loss occurred between June 2007 and June 2008 due to JCU restrictions on tower access. As a result the Discovery Tower system a twelve metre mast was designed and constructed and the second EC system was brought online in December 2008 (Figure 1). The first year of data from the DT system was somewhat patchy due to power system problems. These have since been resolved with >95% data recovery in the last year. In 2007 a weather station was installed on the Discovery Tower which is identical to the CT AWS. In 2010 both systems were brought up to identical hardware standards and communications with the EC systems is now possible using 3G. Complete data analysis in EC studies requires post-processing of the raw fluxes and one of the first major activities was to write the Matlab<sup>®</sup> code for quality control and gap-filling of the fluxes.



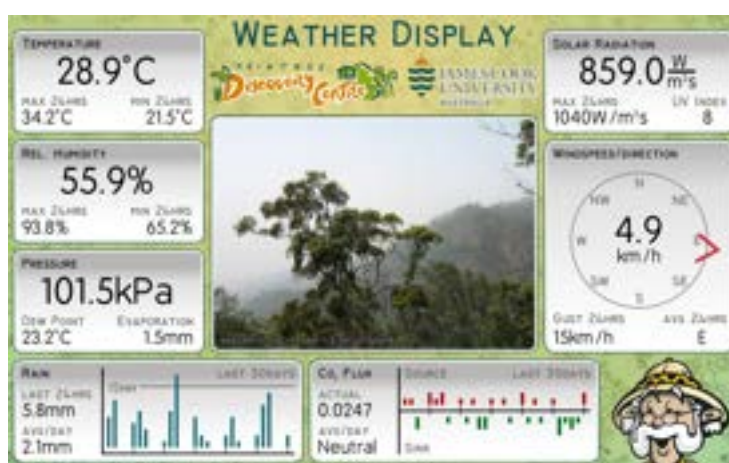
**Figure 1:** Eddy covariance (EC) and weather station instrumentation on the Discovery Tower.

## Additional measurements

In July 2007 a campaign volatile organic chemical (VOC) study was commenced in collaboration with the University of Helsinki (T. Suni and M. Kulmala). The methodology used a diaphragm pump to pull air known quantities of air through an adsorbent cartridge bed; an ozone filter was used to remove possible interference from this strong oxidant. The cartridges were shipped back to Finland and analysed using thermal desorption and GC-MS techniques.

In the second part of the collaboration with the University of Helsinki several instruments were used to assess the aerosol formation characteristics of the lowland rainforest. An Aerosol Ionisation Spectrometer (AIS) was used to measure number densities from very small particles through to medium sized ones that characterise an aerosol formation event. The instrument was operated from inside an air-conditioned office with the sample inlet placed in proximity to the forest for two months starting in early July 2007.

In collaboration with Professor Michael Bird in May 2009, JCU Honours Student Kalu Davies collected soil CO<sub>2</sub> fluxes from sixteen soil collars located inside the 1Ha plot. The soil fluxes were measured using a portable LICOR LI-8100 automatic chamber. The collars were located in sites selected for potential maximum variability in soil fluxes. In addition to the soil fluxes volumetric water content and temperature were also measured.



**Figure 2:** Real time weather and flux display at the Daintree Discovery Centre.

In 2010 a phenocamera was installed on the CT tower logging digital images of the canopy back to the EC system computer on a two-hour schedule. At the Discovery Tower a screen display in the visitor centre is used to present live data from the EC system and weather station direct to the public. In 2010 this was reprogrammed using Python-Webgen, the new platform has proven much more stable (Figure 2). Two additional noticeboards presents information and results from the MTSRF project alongside this display.

## Results and discussion

### *Flux and ancillary measurements*

At Cape Tribulation the flux data collection commenced in March 2001 and as such each flux year covers March to February of the subsequent year. Daytime fluxes were quantitatively analysed as the Canopy Crane tower is located in complex topography. Table 1 reveals that the daytime carbon flux at the site is dramatically reduced in 2002 and 2003 which were years of significant drought for most of Australia (El Niño).

The triggers to the observed decreases in the carbon flux appears to be a reduction in the amount of water available in the wet half year December to May (<2m BOM, Bureau of Meteorology Cape Tribulation station 31012). This rainfall ensures that the soil is saturated and recharges the aquifer. As indicated in Objective (c) at the end of the dry season the soil is placed under such high water potential that it is not possible for the trees to extract

substantive water from the soil. At that point the canopy trees are either reliant on water from the underlying aquifer or make use of storage water in their tissues. Of note in the Table 1 is the relative invariance in the latent heat (water vapour) flux between the years of the drought and normal years. This would appear to be driven by incoming radiation, the net radiometer went on-line in 2004 and the AWS in 2005 precluding further analysis.

Close inspection of the carbon flux data indicates that in the years of low water availability (2002, 2003) (Table 2) the daytime carbon flux is reduced as the photosynthetic component of the net flux is diminished.

In years of normal water availability (BOM 3.9m) an average daytime flux of around  $-6.15 \mu\text{mol}/\text{m}^2/\text{s}^{-1}$  is achieved; the sign is negative indicating that the forest is fixing carbon. The balance between photosynthesis and respiration is in favour of photosynthesis during the daylight hour.

Table 2 presents a comparison between the rainfall at the Bureau Station at Masons store (BOM) and that found on site at the Cape Tribulation (CT). More data is needed but the MAP at CT ( $\approx 5.3\text{m}$ ) is clearly much higher than the MAP observed at the BOM station (3.9m). The distance between the two weather stations is 1.3km across a relatively low ridge, despite the proximity and similar elevation the local topography is sufficient to substantially change the climatic conditions. This has significance for the modelling of climate refugia in the region. The modelling approaches typically use climate surfaces which are dependent on latitude, longitude and elevation. Work is in progress to establish the differences between ANUCLIM a widely used climate surface package and the data collected at the Cape Tribulation and the Daintree Discovery Centre AWS.

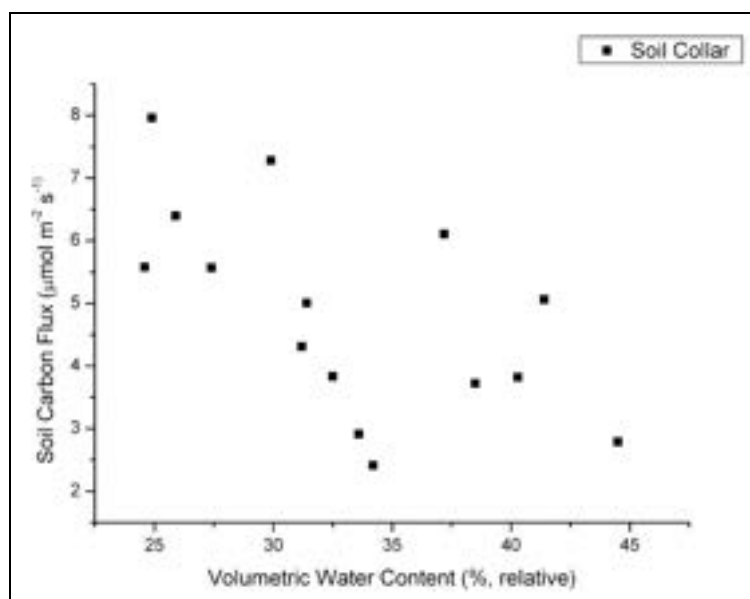
At night respiration is the process responsible for carbon dioxide fluxes. Due to the topography at the crane site we are unable to measure the nocturnal respiration with the EC system due to drainage flow of  $\text{CO}_2$  from the tablelands above the site. What we have investigated instead are the soil carbon fluxes as the soil microbes are the dominant source of respired  $\text{CO}_2$  at night. Illustrated in Figure 3 is the dependence of soil respiration at CT on volumetric soil water content.

**Table 1:** Average values of daytime Carbon, Latent and Sensible heat fluxes.

| YEAR                                                     | 2001   | 2002   | 2003   | 2004   | 2005   | 2006   |
|----------------------------------------------------------|--------|--------|--------|--------|--------|--------|
| Carbon Flux ( $\mu\text{mol}/\text{m}^2/\text{s}^{-1}$ ) | -5.98  | -4.85  | -4.91  | -6.09  | -6.35  | -6.18  |
| Latent Heat Flux ( $\text{W}/\text{m}^2$ )               | 200.01 | 205.01 | 196.48 | 188.06 | 186.68 | 183.03 |

**Table 2:** Annual rainfall (mm) at Cape Tribulation.

|     | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|-----|------|------|------|------|------|------|------|------|------|
| CT  | -    | -    | -    | -    | -    | 7166 | 5381 | 4518 | 4585 |
| BOM | 3108 | 2430 | 2554 | 4991 | 2738 | 5945 | 4325 | 3901 | 3624 |



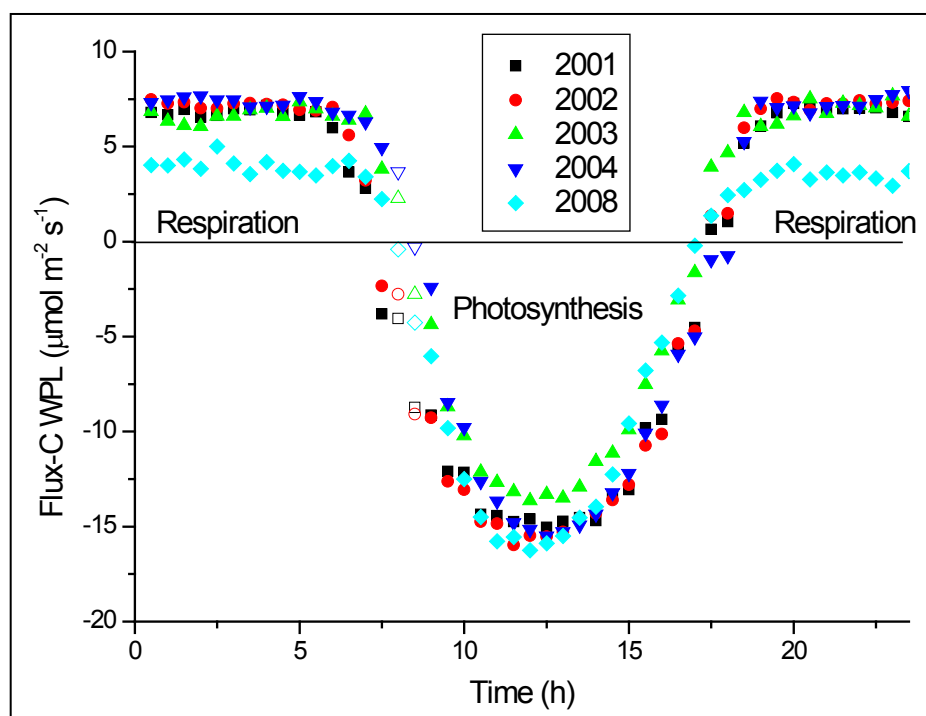
**Figure 3:** Plot of soil fluxes ( $\mu\text{mol/m}^2/\text{s}^{-1}$ ) vs. soil water content (vol. %), May to June 2009.

The soil fluxes obtained in 2009 may be compared to recent results reported from the rainforests of Borneo (Ohashi *et al.* 2008) where at similar soil water content their median values  $4\text{--}6 \mu\text{mol m}^{-2} \text{s}^{-1}$  are found to be quite comparable to those found at Cape Tribulation in 2009. From the current results we can see that respiration would be expected to decrease in the wet season and increase in the dry season (under similar temperature conditions). Further work is to be done later in the year (post-MTSRF) to establish these temperature soil  $\text{CO}_2$  flux relationships in collaboration with Michael Bird (JCU).

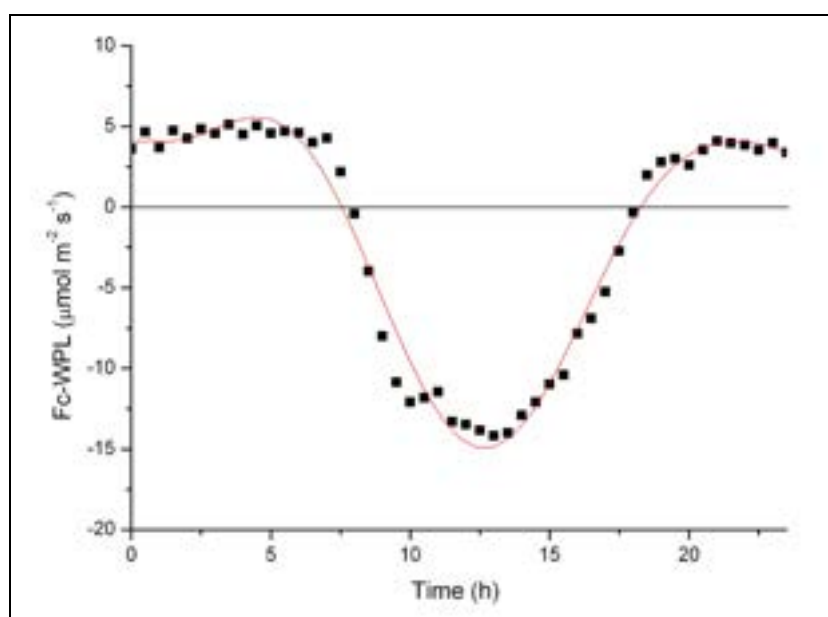
Despite our inability to quantitatively measure the respiration component using the EC instrumentation we are able to semi-quantitatively estimate trends in respiration. To this extent we have plotted annual diurnal trends in carbon flux at the CT site for several of the early years (2001-2004) and a later year 2008 in Figure 4. In 2008 we can see that the photosynthetic dominated part of the curve is similar to previous years whereas the respiratory component has substantially decreased. It appears that the effect of Tropical Cyclone *Rona* which decimated the site in February 1999 was quite pronounced in the early years of the flux station where the decomposition of fallen tree material elevated the respiratory flux. In more recent years respiration has decreased to values that are more typical of other tropical rainforest systems. Due to a change in hardware/software configuration in late 2009 the complete flux year for 2009 has yet to be generated for the Cape Tribulation site.

The results for the CT site in 2008 are similar to the results obtained at the Discovery Tower in 2009 (Figure 5) confirming that our approach which is to use two sites to replicate the eddy covariance results is valid.

The rainfall as seen in Table 2 was essentially identical at the Canopy Crane site in the years 2008 - 2009. Instrumental problems with the Discovery Tower AWS in 2009 has ruled out direct comparison of rainfall between these sites for these two years.



**Figure 4:** Diurnal variation in carbon dioxide fluxes at Cape Tribulation.

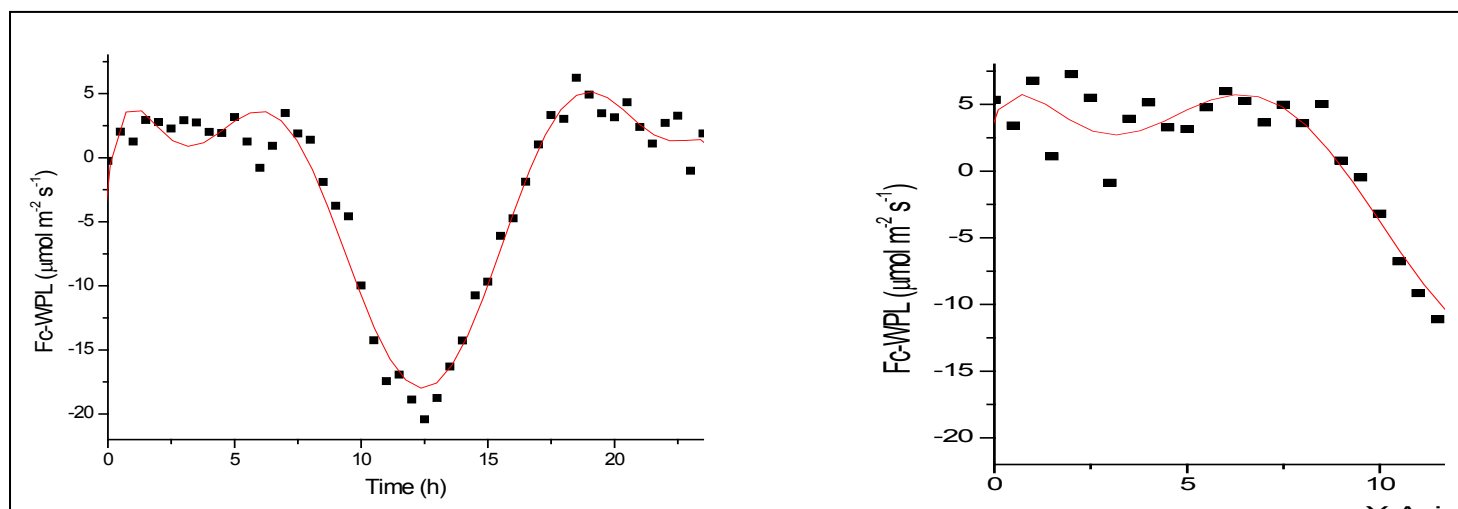


**Figure 5:** Diurnal variation in carbon dioxide fluxes at the Discovery Tower, 2009.

Figure 6 presents carbon flux data for comparable periods in the 2010 wet season at the two flux stations. The Cape Tribulation site received substantially more rainfall than the Discovery Tower site and concomitant with this was a reduction in the available solar energy for photosynthesis (due to cloud cover). The value of the replicate sites is now immediately apparent as we have been able to narrow down the process responsible for the reduction in photosynthesis in the wet season to an increase in cloudiness/rain. For accurate predictions of change in range of a forest type in the Wet Tropics not only do we need to include

precipitation and rainfall but also any change in cloudiness which is not accompanied by rainfall as this can dramatically change plant performance.

As part of the standard Ozflux community participation the flux data sets for 2001 - 2006 have been deposited on the Ozflux web site to date: <http://www.dar.csiro.au/lai/ozflux/monitoringsites/index.html>. Navigate to *Cape Tribulation / Data Sets*.



**Figure 6:** (Left) Discovery Tower carbon fluxes, January to March 2010 (solar average  $12000 \text{ W m}^{-2} \text{ y}^{-1}$ ). (Right) Cape Tribulation carbon fluxes, January to March 2010 (solar average  $9000 \text{ W m}^{-2} \text{ y}^{-1}$ ).

### Additional measurements

#### Volatile Organic Compounds

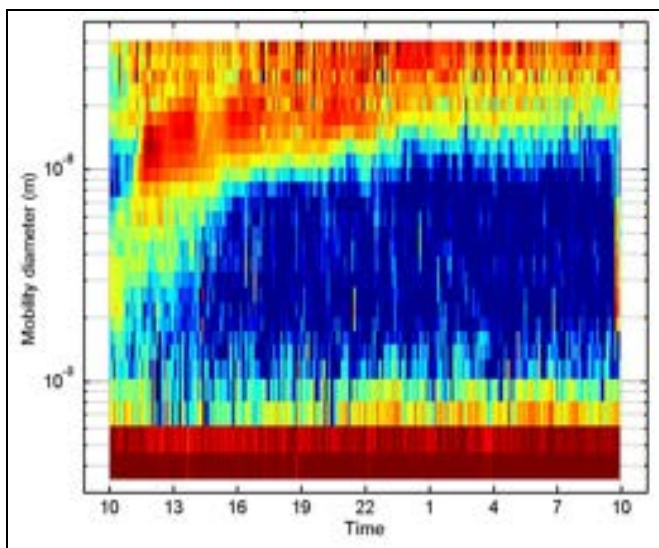
The first VOC (Volatile Organic Compound) concentrations in the lowland rainforest of the Daintree were carried out in July 2007 as part of a joint collaboration with the University of Helsinki. The results were somewhat surprising in that from a highly diverse tropical rainforest one could expect a large range of VOCs; instead only a small number of VOCs were found in appreciable concentration. Other than isoprene and  $\alpha$ -pinene, two compounds which were expected to be present in measurable quantities (Greenberg *et al.* 2004), there were significant quantities of *n*-decane and toluene found in the cartridge samples that were analysed. The Canopy Crane air samples contained more identified VOCs than the Discovery Tower samples where only eight VOCs were found. Diurnal fluctuations in isoprene showed an increase in concentration throughout the morning with peak mixing ratios of  $2.7 \mu\text{g/m}^3$  occurring at mid-day when the air-temperatures and light intensity were at their respective maxima. Lower concentrations of isoprene were found in the air samples collected at the top of the Discovery Tower than found on the ground at the Canopy Crane site.

#### Aerosol particles

In the second part of the collaborative study with the University of Helsinki several instruments were used to assess the aerosol formation / sink characteristics of the lowland rainforest. Figure 7 illustrates a formation event occurring outside the forest on 9-10 July 2007 as measured using the AIS spectrometer. The event started in earnest around 11:00am on the morning of 9 July where a sudden increase in particles with diameters 10-100nm is observed, the number of particles then decreased over the next 24 hours. As the measure-

ments were made outside the forest it is not clear yet if the particles that form originate from photochemically transformed VOCs or from the marine coastal background.

Our interest in VOCs and aerosols is prompted by their importance in cloud formation and in the carbon cycle. While the VOCs are present in trace concentrations in forests it has been suggested that VOC emissions play an important role in balancing the net primary productivity of tropical forests (Crutzen *et al.* 1999). It is likely that VOC emissions will alter when the forest is placed under climatic stress. Hence knowledge of the chemical VOC fingerprint of the forest under normal conditions is important so that we have another future quantitative indicator of changes in forest function.



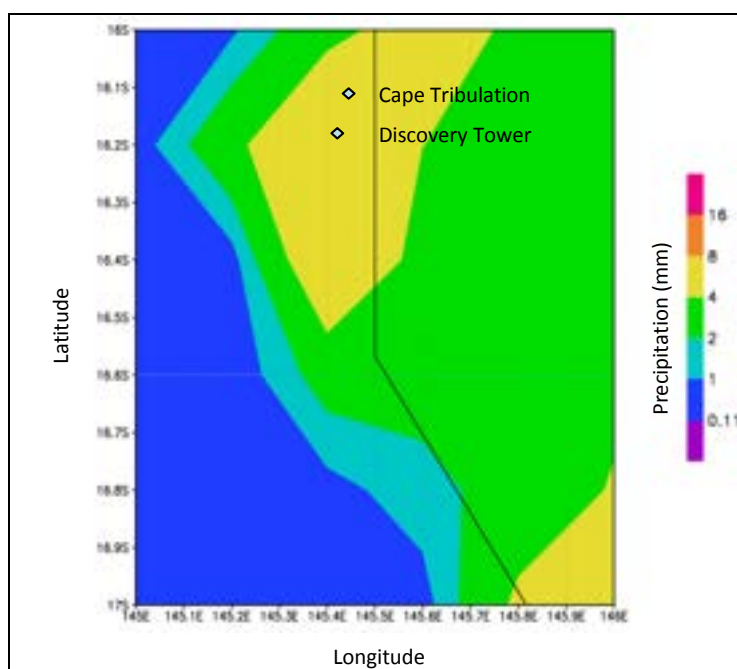
**Figure 7:** Aerosol formation, 10 July 2007, recorded outside the forest, ten metres from the edge. Colour scale indicates relative number density: Red = High; Orange-yellow = Medium; Blue = Low.

It is known that secondary organic aerosol (SOA) particles form from biogenic VOC in the presence of sunlight. It is also known that such SOA particles may participate as Cloud Condensation Nuclei (CCN) those particles that are responsible for cloud formation. In the context of the MTSRF program providing more information on the how the lowland rainforests may be involved in local cloud formation is important as it is 'cloud stripping' which provides the microclimate for the wet upland forests and which provides the base flow for the many river systems with their headwaters in the upland forests. The preliminary results from this sub-project are therefore contributing towards developing an understanding of the origin of the precursor aerosol particles involved with cloud formation and the role of the forest as a sink for these particles.

### ***Climate Change***

Latent heat fluxes, as outlined in Table 1, were shown to be relatively invariant between years.

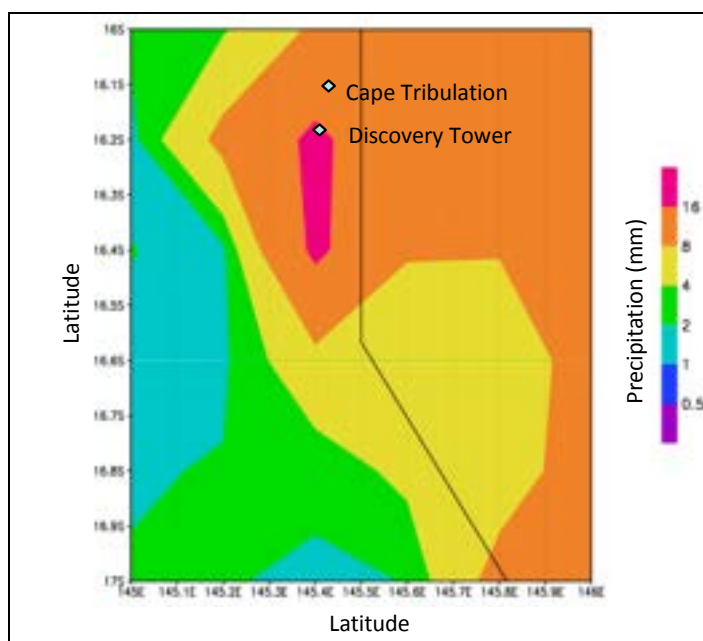
Further analysis of the latent heat flux data when converted to mm of evapotranspiration for the last six years of data collection has indicated that the forest requires around 4.8mm of water to sustain daily



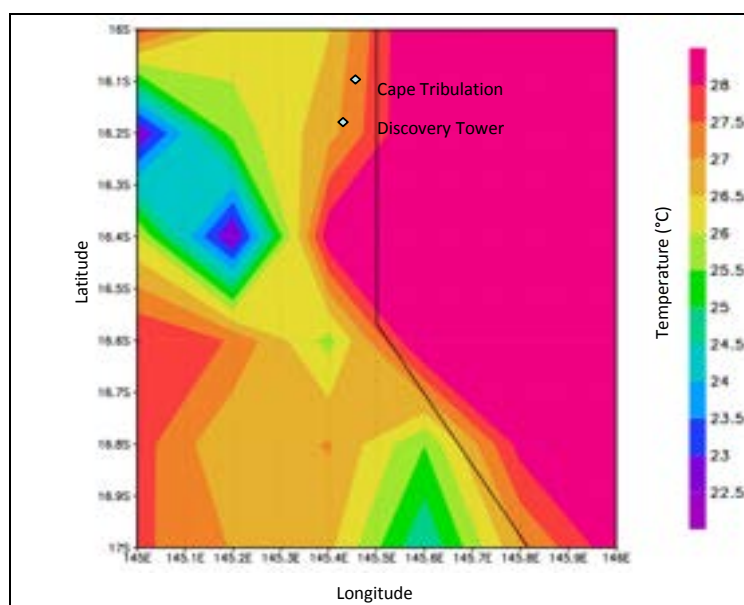
**Figure 8:** Predicted precipitation (mm) for 'dry period' June, July and August in the year 2080 (MTSRF Project 2.5ii.1).

evapotranspiration. The average daily input per month from precipitation is generally more than sufficient to maintain forest productivity. The exception is during the dry period from June to November where the precipitation input is typically around 4mm day or less. Fortunately it appears from the most recent climate change model estimates (MTSRF Project 2.5ii.1) that this dry period will not get substantially drier (Figure 8), most of the drying effects will occur instead in the wet season.

Figure 9 (precipitation in the wet season) shows that things are looking far less desirable for the rainforest. Precipitation currently is averaging 17.5mm/day throughout the wet period from December to May. By the year 2080 this is predicted by the ensemble of three current models to be between 8-16mm/day. Given the caveats of our discussion on the differences in rainfall between the BOM station and the CT station there is some room for some optimism, in particular as the Discovery Tower lies on the edge of the region that will have less change in precipitation. Nevertheless, we have established that it is the wet season rainfall that the forest is reliant on; when rainfall drops below two metres then the forest becomes stressed. Now we have a clear indication that this is the rainfall resource that will be hardest hit during climate change.



**Figure 9:** Predicted precipitation (mm) for 'wet period' March, April and May in the year 2080 (MTSRF Project 2.5ii.1).



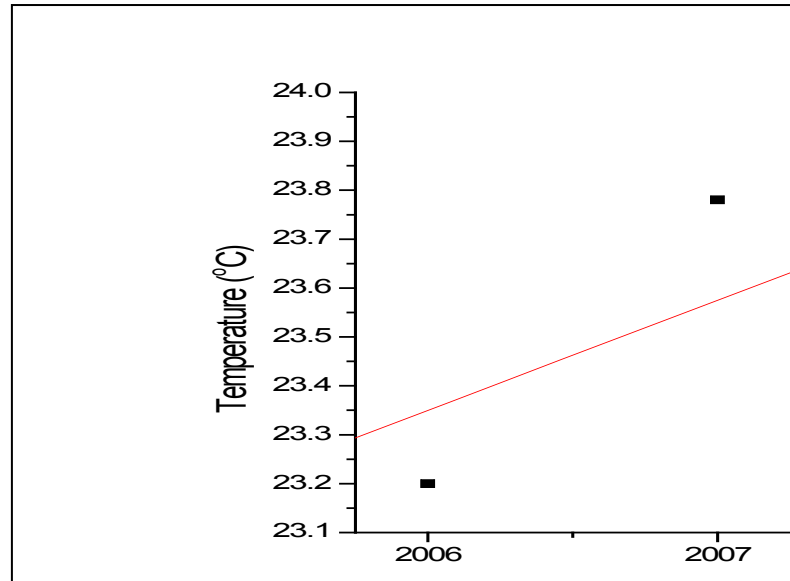
**Figure 10:** Predicted Mean Annual Temperature for the year 2080 (MTSRF Project 2.5ii.1).

A distinct change is to be predicted for annual temperature (Figure 10). Currently the Cape Tribulation site has a Mean Annual Temperature (MAT) of 23.9°C; by 2080 the temperature in this region of the Daintree is predicted to increase into the 27-27.5°C band. This will result in a substantive change of 3.6°C in the MAT. The effects are more pronounced in the wet season in the daily  $T_{max}$  values, this will not be prove to be a major stressor for the forest as the VPD is not as high in the wet season. It is an increase in the  $T_{min}$  values throughout the year that is largely responsible for the increase in MAT. Potentially this will increase respiration.

Figure 11 indicates the first measured increase in temperature in the Daintree rainforest that has been reported, 0.6°C from 2006-2009. The accuracy of the results are near the limits of precision of the temperature sensor but the trend is the same when compared against other sensors on site and with the small data set acquired on the Discovery Tower. These then are the first indications of climate change in the Daintree Region.

### Acknowledgements

We are grateful to the Bureau of Meteorology, Cairns for providing weather data. Drs John McGregor and Suppiah Ramasamy (CSIRO Marine and Atmospheric Research) provided the climate simulation data as output from MTSRF Project 2.5ii.1.



**Figure 11:** Temperature record for the Cape Tribulation site.

## **Objective (b) – Plant Physiology**

**Principal Investigator: Dr Will Edwards, James Cook University**

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### **Introduction**

Rainforest ecosystems are reliant on the plant community for their success or failure. In the lowland rainforests of the Daintree region, canopy trees have adapted through the successive climatic regimes of recent geological history. This sub-project (Objective b) investigated the productivity status of the forest – the key to a process-based understanding of future climate induced changes in the ecosystem.

In 2007, Dr Peter Franks and colleagues commenced measurements of tree growth increments and forest production and turnover. Tree growth was estimated from dendrometer bands placed on almost all ( $n=170$ ) individual trees greater than 10cm DBH at the time of commencement. Forest productivity/turnover was assessed monthly as dry mass of plant components (wood, leaf, fruits-and-flowers) in  $25 \times 1\text{m}^2$  litter traps placed at random positions within a 1ha area of forest directly underneath the Australian Canopy Crane at Cape Tribulation.

### **Activities**

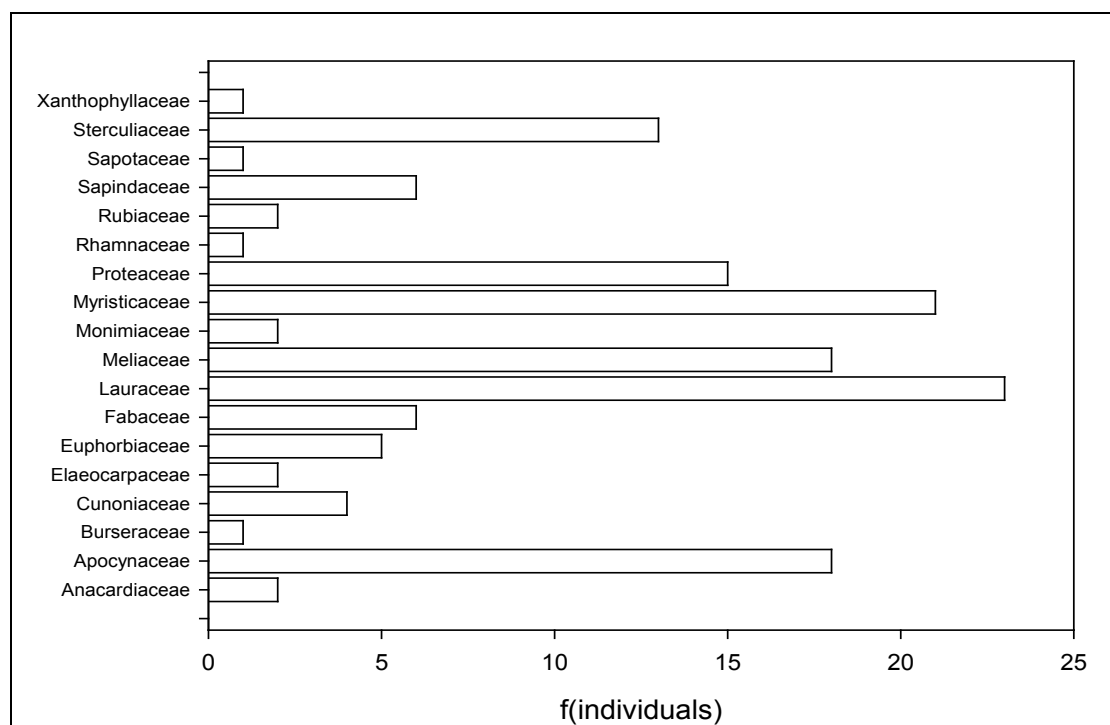
In January 2007, 25 leaf litter traps were installed in a  $25\text{m} \times 25\text{m}$  grid across the 1ha plot at the Canopy Crane site. Collection of leaf litter fall occurred fortnightly; was dried at 70 degrees until constant weight; sorted into four categories (leaf, woody material, reproductive components, and 'other') and then weighed. Collection continued until December 2009, resulting in three years' litter fall data.

In March the same year, dendrometer bands were placed on all trees within the 1ha crane plot with a diameter greater than 25cm. This size class was chosen as it represented the trees with greatest biomass on the plot. This resulted in 170 trees being banded and incorporated 39 species. Annual measurements of diameter growth were then taken in 2008, 2009 and 2010.

The rate of canopy closure was monitored using Leaf Area Index (LAI) measurements. Hemispherical photographs were taken using a Sony  $\alpha$ -700P digital camera with an attachable fisheye lens. The images were collected at each of the 25 litter traps beginning in April 2008. Initially, these 25 photographs were to be repeated annually, however the detection of seasonal changes in canopy closure became of interest and thus a more frequent sampling period was necessary. Consequently, images were collected at four monthly intervals in 2009 and will continue to be collected at this sampling frequency.

## 1. Dendrometer measurements of stem incremental growth

In total, 170 trees with initial stem diameters at breast height greater than 25cm were selected in 2007. As expected, representation of individuals within species and families are not equal (Figure 12, Appendix 1). These trees come from 18 plant families and are typical components of this forest type.



**Figure 12:** Breakdown of individuals within 18 plant families included in the dendrometer (growth increment) study.

## 2. Estimating above-ground biomass from tree incremental growth

Tree incremental growth has been assessed on five occasions: March 2007, March 2008, September 2008, May 2009 and March 2010. Thus there are four between-census intervals over which to make comparisons. All measurements and analysis were undertaken using AGB unless otherwise stated. AGB, rather than incremental increase in diameter at breast height (DBH) was selected because changes in size are not strictly reflective of change in biomass. This is because species differ in wood density, and because a small increment in DBH in an initially large stem will produce a much greater increase in biomass than an equal DBH increment in an originally small stem. To examine increase in biomass we used records for estimated wood density for all trees. Two individual trees had died and were removed.

Density measurements were taken from the Australian Greenhouse Office (AGO) and CSIRO Forestry and Forest Products (FFP) [Updated Australian Species Wood Density Database](http://www.climatechange.gov.au/ncas/reports/tr18final.html) – July 2003 Woody Density Phase 1 – State of Knowledge National Carbon Accounting System – Technical Report No. 18 (available download database from <http://www.climatechange.gov.au/ncas/reports/tr18final.html>), and also from Dr Daniel Metcalfe (CSIRO Atherton).

We calculated net change in above-ground biomass (AGB) using the allometric models of Chave *et al.* (2005). We calculated AGB based on the allometric model for wet forest stands and without knowledge of individual plant height (H) distributions:

$$AGB_{est} = \rho * \exp(-1.239 + 1.980\ln(D) + 0.207(\ln(D^2)) - 0.0281(\ln(D^3)))$$

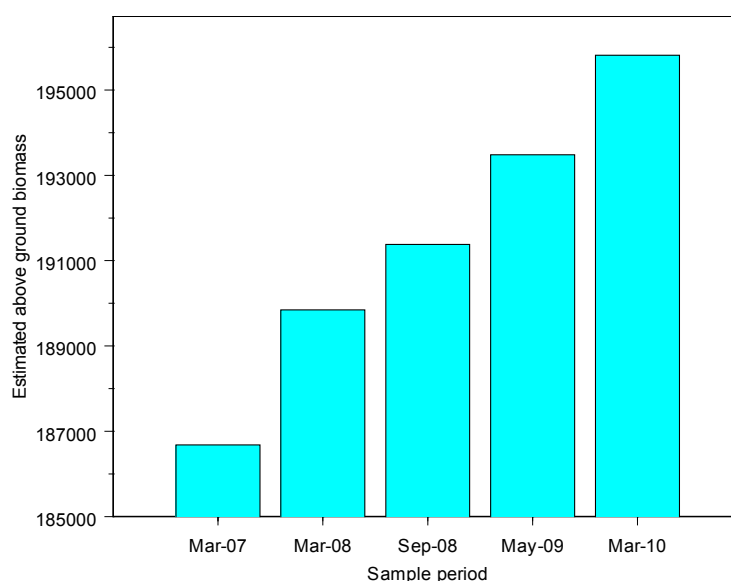
where  $\rho$  is density (estimated as  $\text{g.cm}^{-3}$ ) and  $D$  is stem diameter.

Because tree incremental growth was assessed on the five above-mentioned occasions, but the time separating assessments are not constant, change in AGB between time intervals was expressed on a per-month basis. We also calculated the absolute change in biomass across the whole 36 month study period (March 2007 to March 2010). We began by examining absolute size increase (in above-ground biomass (AGB)) across all trees. We then tested for differences in mean monthly rates of increase between census periods, and compared these to overall growth rates across the study period. The distribution of changes in AGB across intervals were not normal, and included both zero and negative values. We therefore used a simple transformation ( $\ln +0.1$ ) to help normalise the distributions.

Since there were no differences in the magnitude of changes in AGB between time intervals, we used the total increase (determined from the entire 36 month study period to test for differences between plant families. Families were included if they were represented by five or more individuals and again data were  $\ln (+0.1)$  transformed prior to analyses.

## Results and discussion

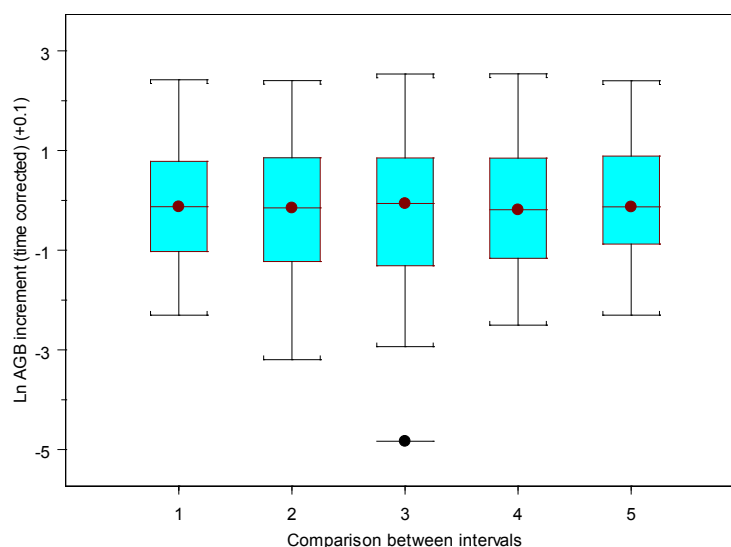
Across the entire study period, there was an overall increase in  $AGB_{ets}$ . At the time of commencement, the  $AGB_{ets}$  was 186.7 t, which increased (more-or-less) uniformly (Figure 13). The  $AGB_{ets}$  for March 2010 was 195.8t (an overall increase of 0.9t). The area encompassed by the canopy crane is approximately 1ha, so these values can be considered in  $\text{t.ha}^{-1}$ . Furthermore, these estimates are not outside of estimates reported by Chave *et al.* (2005). In Chave *et al.*, allometric models were used to estimate AGB from 20 data sets. These data sets differed in number of trees (range 8-360) and in total Biomass (range 3240-147,928), and number of trees and total Biomass are not strictly related. We expressed Biomass reported in Chave *et al.* as a function of number of trees sampled, and performed this for our dataset also (essentially expressing the 'mean' biomass per tree). These values in Chave *et al.* (2005) ranged from 44.3 to 4440.2, and our values are well within this range (Cape Tribulation) 1178.87. The value also sits well inside the recent estimate of biomass for the plot of 270  $\text{t ha}^{-1}$  (Liddell *et al.* 2007) as the dendrometer bands are only placed on the largest size class and there are currently 704 trees in the above 10cm size class. It is well known that the largest size classes contain the most biomass in the forest, in this case then the >25cm size class is increasing in biomass indicating that the forest is storing carbon above ground.



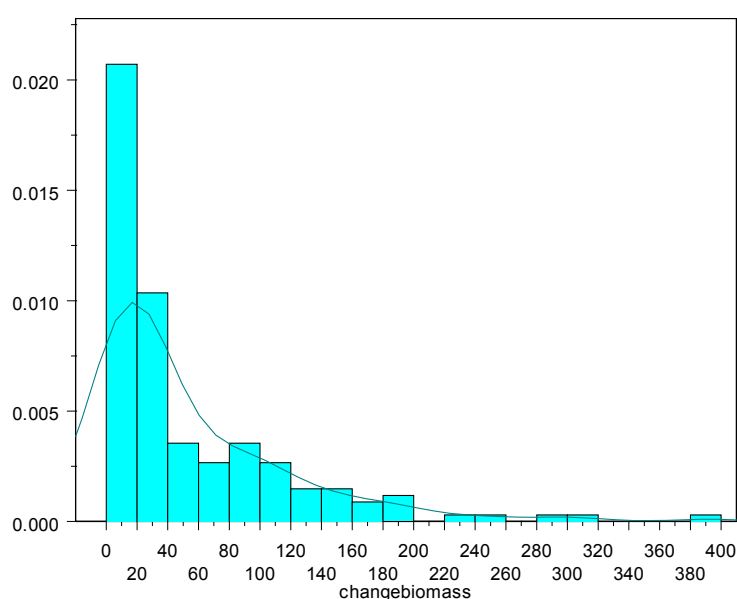
**Figure 13:** The estimated above-ground biomass ( $AGB_{est}$ ) for the Cape Tribulation Canopy Crane site over five sampling periods. Note: Times between sample periods are not equal. Samples are from 170 individual trees >10cm dbh in March 2007.

Incremental increase in AGB was consistent across all time intervals when expressed as a function of time between samples (Figure 14). There was no significant difference in  $\ln$  AGB increment for any period (One-way ANOVA,  $F_{4,827} = 0.233$ ,  $P = 0.92$ ). Post-hoc pair-wise comparisons also revealed no differences between any two time intervals (Appendix 2). Because of this, the monthly  $AGB_{est}$  calculated across the entire sample period (comparison 5 in Figure 14), was not different from the monthly AGB calculated between and two consecutive surveys.

While overall mean  $\ln$  changes in AGB were not different across time, there were differences in the amount of AGB increase within each species (Figure 15). The distributions of changes in DBH between species were not normal (Figure 15) and again,  $\ln$  transformation was used to help normalise the data.



**Figure 14:** Box plot for mean monthly (time corrected)  $\ln$  AGB increment for sequential sampling periods. On x-axis: 1 = March 2007 to March 2008; 2 = March 2008 to September 2008; 3 = September 2003 to May 2009; 4 = May 2009 to March 2010. 5 is mean monthly (time corrected)  $\ln$  AGB for entire 36 months of study.



**Figure 15:** The probability density distribution of absolute changes in biomass (36 months, all stems).

**Table 3:** Species, wood density, number of individuals at end of study, mean change in DHB and Mean change in AGB for 37 species included in biomass growth experiment Cape Tribulation Canopy Crane site.

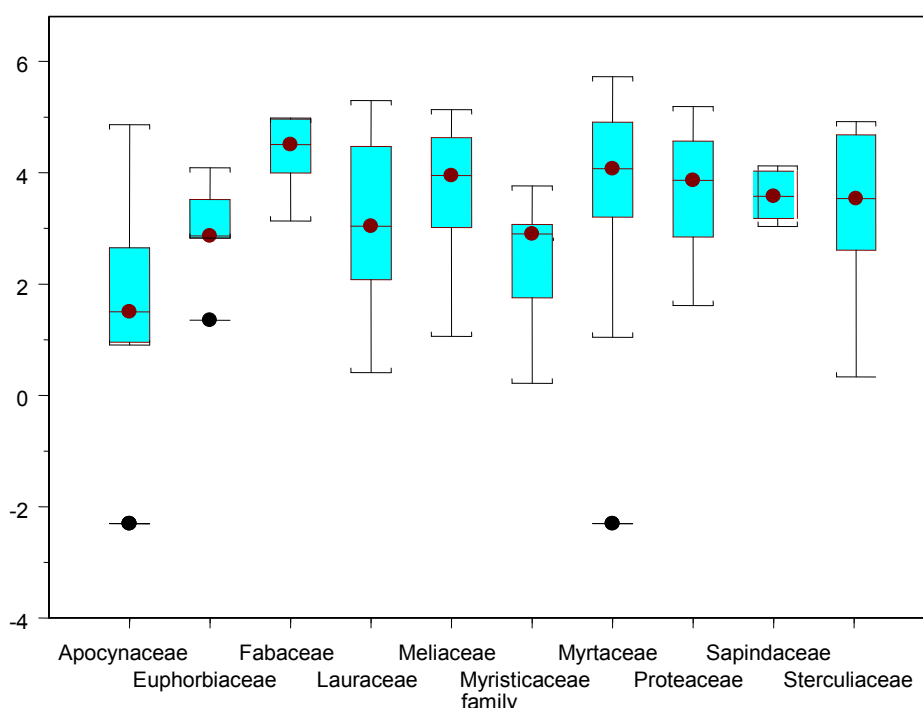
| Species                             | Wood density | n(2010) | mean change dbh 2007-2010 | mean change AGB 2007-2010 |
|-------------------------------------|--------------|---------|---------------------------|---------------------------|
| <i>Acmena graveolens</i>            | 0.489        | 11      | 1.1589                    | 73.641                    |
| <i>Alstonia scholaris</i>           | 0.333        | 14      | 0.282                     | 41.233                    |
| <i>Antirhea tenuiflora</i>          | 0.536        | 1       | 2.2918                    | 154.9                     |
| <i>Argyrodendron peralatum</i>      | 0.653        | 13      | 0.8587                    | 81.65                     |
| <i>Austromuellera trinervia</i>     | 0.565        | 1       | 0.5092                    | 2.746                     |
| <i>Cardwellia sublimis</i>          | 0.461        | 11      | 1.1945                    | 64.807                    |
| <i>Castanospermum australe</i>      | 0.621        | 6       | 1.1273                    | 71.8512                   |
| <i>Cleistanthus myrianthus</i>      | 0.711        | 4       | 0.5689                    | 44.1966                   |
| <i>Cryptocarya grandis</i>          | 0.677        | 3       | 0.3236                    | 35.993                    |
| <i>Cryptocarya hypospodia</i>       | 0.525        | 1       | 3.1035                    | 70.4438                   |
| <i>Cryptocarya mackinnoniana</i>    | 0.717        | 6       | 0.1618                    | 23.502                    |
| <i>Cryptocarya murrayi</i>          | 0.645        | 1       | 0.1432                    | 18.106                    |
| <i>Doryphora aromatica</i>          | 0.461        | 2       | 0.1671                    | 12.563                    |
| <i>Dysoxylum alliaceum</i>          | 0.549        | 4       | 1.0583                    | 32.0098                   |
| <i>Dysoxylum arborescens</i>        | 0.415        | 1       | 0.7639                    | 176.4106                  |
| <i>Dysoxylum papuanum</i>           | 0.605        | 5       | 0.9549                    | 42.947                    |
| <i>Dysoxylum pettigrewianum</i>     | 0.709        | 7       | 1.039                     | 88.2485                   |
| <i>Elaeocarpus angustifolia</i>     | 0.433        | 2       | 6.637                     | 72.773                    |
| <i>Emmenosperma cunninghamii</i>    | 0.705        | 1       | 0.366                     | 26.113                    |
| <i>Endiandra microneura</i>         | 0.677        | 10      | 1.0138                    | 46.3915                   |
| <i>Ganophyllum falcatum</i>         | 0.705        | 1       | 0.6207                    | 38.761                    |
| <i>Gillbeea whypallana</i>          | 0.612        | 4       | 1.126                     | 51.0422                   |
| <i>Litsea leefeana</i>              | 0.421        | 1       | 0.3342                    | 23.622                    |
| <i>Musgravea heterophylla</i>       | 0.557        | 3       | 0.3289                    | 31.679                    |
| <i>Myristica insipida</i>           | 0.461        | 21      | 0.4492                    | 36.72                     |
| <i>Neonauclea glabra</i>            | 0.693        | 1       | 0.2228                    | 31.7644                   |
| <i>Palaquium galactoxylon</i>       | 0.461        | 1       | 0.4456                    | 21.4506                   |
| <i>Rockinghamia angustifolia</i>    | 0.653        | 1       | 0.4456                    | 33.689                    |
| <i>Semecarpus australiensis</i>     | 0.373        | 2       | 0.4695                    | 4.466                     |
| <i>Synima cordierorum</i>           | 0.773        | 5       | 0.5411                    | 96.1928                   |
| <i>Syzygium cormiflorum</i>         | 0.701        | 1       | 0.7321                    | 15.544                    |
| <i>Syzygium gustavioides</i>        | 0.557        | 9       | 0.684                     | 62.1775                   |
| <i>Syzygium kuranda</i>             | 0.709        | 1       | 0.8276                    | 84.0399                   |
| <i>Syzygium sayeri</i>              | 0.637        | 7       | 1.8757                    | 25.8488                   |
| <i>Toona ciliata</i>                | 0.373        | 1       | 0.07957                   | 143.0619                  |
| <i>Wrightia laevis ssp. millgar</i> | 0.469        | 4       | 0.2984                    | 93.40288                  |
| <i>Xanthophyllum octandrum</i>      | 0.653        | 1       | 0.3501                    | 0                         |

Species differed in mean AGB increment (Table 3), but due to restrictions on sample sizes in most species (see Figure 12) no assessment of between species differences were possible.

Grouping individuals at the family level resulted in ten families that had greater than five individuals (Apocynaceae, Euphorbiaceae, Fabaceae, Lauraceae, Meliaceae, Myristicaceae, Myrtaceae, Proteaceae, Sapindaceae and Sterculiaceae). There were significant differences between families in AGB increment over the study period ( $F_{9, 143} = 4.609$ ,  $P < 0.001$ ) (Figure 16).

The mean estimate across all families was 3.11, while individual families varied (i.e. Apocynaceae = 1.42, Euphorbiaceae = 2.93, Fabaceae = 4.34, Lauraceae = 3.08, Meliaceae = 3.63, Myristicaceae = 2.36, Myrtaceae = 3.58, Proteaceae = 3.73, Sapindaceae = 3.58, Sterculiaceae 3.46). There were six significant posthoc pair-wise comparisons. These significant comparisons all included Apocynaceae, which had a significantly lower mean AGB increment than Fabaceae, Lauraceae, Meliaceae, Myrtaceae, Proteaceae and Sapindaceae (Appendix 2). No other comparisons were significant (Appendix 2). Thus one Family, Apocynaceae, appear to have increased significantly less than in terms of AGB than 6/9 others, but mean incremental AGB were similar for individual trees of all other families.

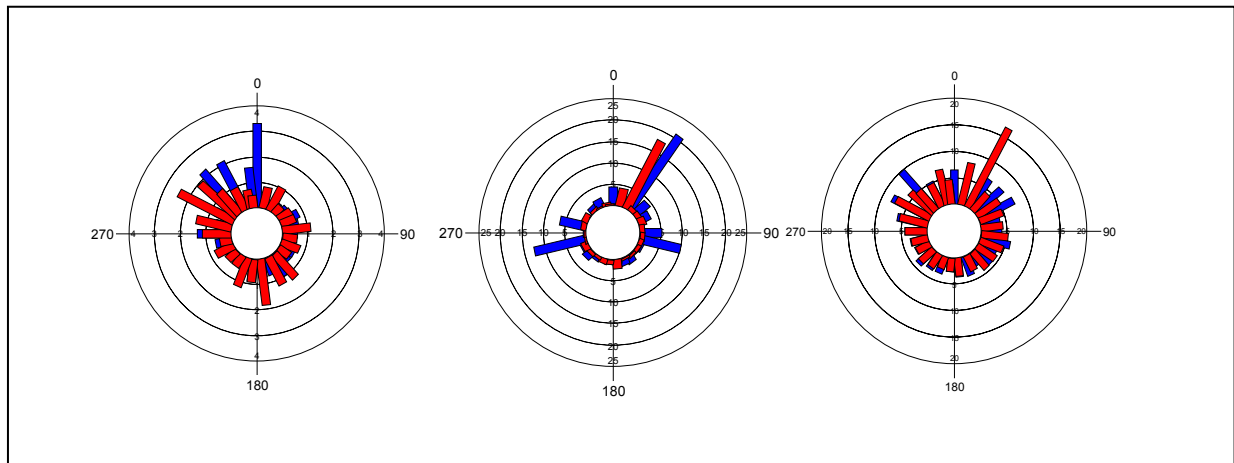
We considered two possibilities to explain differences in AGB increment. First, species (and thus Families) with higher wood densities may grow slower, and second, that initial size at March 2007 may influence AGB increment. While there was a negative relationship between AGB increment and wood density among species, and a positive relationship between AGB increment and initial dbh, neither were significant (AGB vs wood density  $F_{1,35} = 1.37$ ,  $P = 0.25$ ; AGB vs initial dbh  $F_{1,35} = 2.16$ ,  $P = 0.15$ ). Perhaps there is no simple linear relationship between these predictor and response variables and a more complex model fitting approach may be needed. Further investigation that would increase the sample sizes for species and families would be required to explore these relationships with enough residual degrees of freedom to ensure robust conclusions (Zurr *et al.* 2009).



**Figure 16:** *ln* AGB increment (time corrected) (+0.1) for 10 plant families represented by five or more individuals.

### 3. Litter trap to monitor and compare carbon turnover across species

We performed an initial (preliminary) analysis of the litter trap data (Figure 17). The data are circular by nature and must be analysed using a circular statistical procedure.



**Figure 17:** Preliminary analysis (circular histograms) of litter trap data. Results are the mean weight (mg) from 25 litter traps samples (approx.) two weekly intervals. Figures are (from left) flowers and fruit, wood, and leaf. Histograms are blue (2007) and red (2008).

### 4. Leaf Area Index (LAI) measurements

Commencing in 2009 LAI measurements were carried out using hemispherical photography. The LAI values for April 2009 were 3.9 (LAI 4 ring) and 3.5 (LAI 5 Ring) these values dropped to 3.5 (LAI 4 ring) and 3.2 (LAI 5 Ring) in April 2010 which appears to correlate with the large increase in rainfall/cloudiness. The BOM data were 328mm in April 2009 and 1153mm in April 2010. These changes are not distinguishable statistically due to the magnitude of the variability between the 25 traps. An LAI of 3.5 is low compared to the rainforests of the Amazon, where values may be higher than 5, but this is due to the lower stem density and basal area of the lowland rainforest. These are preliminary data but they indicate that LAI will become part of the annual measurement/analysis cycle for the Cape Tribulation station as LAI is able to contribute to our understanding of the dynamic state of the vegetation in the rainforest.

## **Objective (c) – Below-ground Fluxes of Carbon and Water**

### **Principal Investigator: Dr Paul Nelson, James Cook University**

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#### **Part (i) Below-ground fluxes of water**

##### **Introduction**

The hydrology of tropical forests is of critical importance for ecosystem functioning and response to climate change. Transpiration has been shown to be dependent on solar radiation and atmospheric demand (McJannet *et al.* 2007). However, little is known about the uptake of water. Temporal patterns of water uptake are likely to determine the response of forest to climate change climate, whether that involves wetter, drier or more variable conditions. The aim of this work was to determine uptake rates and the factors controlling them in a lowland tropical rainforest at Cape Tribulation.

##### **Activities**

The study site was the Australian Canopy Crane Research Facility, near Cape Tribulation. The forest is complex mesophyll vine forest (Tracey and Webb 1975).

The soil is an Acidic, Dystrophic, Brown Dermosol (Isbell 1996) with many (20-50%) cobbles and stones throughout the profile. The soil is developed in colluvium from the metamorphic and granitic mountains to the west. The colluvium appears to have originated in a catastrophic collapse, as it consists of randomly mixed particles ranging in size from micrometres to metres. Sieved (<2mm) samples were analysed, using methods described by Rayment and Higginson (1992) for exchangeable Ca, Mg, K and Na (Method 15A1), exchangeable acidity and Al (Method 15G1), Colwell extractable P (Method 9B2), total C (Method 6B4), total N (Method 7A7), electrical conductivity (EC) and pH (both in 1:5 soil:water extract) and particle size distribution. As the soil has a high content of stones, the volumetric proportion of soil and rock was determined at several depths. The total volume of each depth increment was determined by pouring measured volumes of sand into a pit as it was excavated. The excavated soil was sieved (2mm); and material passing through the sieve was called soil. Material that was retained on the sieve was mechanically tumbled for 45 minutes in order to break apart aggregates of soil and to separate soil from the rocks. The tumbled material was sieved again through a 2mm sieve and the material retained was separated into roots and rocks. All materials were weighed and the water content of the soil was determined. Using a calibrated 20L bucket, the volume of rocks (pre-wet to prevent loss of water by absorption) was measured. The volume of soil in each layer was calculated by subtracting rock volume from the volume of the excavated hole. Variations in the ratio of soil:rock across the canopy crane site were measured in a survey described in Part (ii) of this section (page 26).

A pit was dug to 1.5m depth in July 2007 and monitoring probes were installed at 0.1, 0.75 and 1.5m depths. At each depth there were three-time domain reflectometry probes (Campbell Scientific CS616) to measure volumetric water content, three gypsum blocks (Measurement Engineering Australia GBHeavy, except at 0.1m depth where there were only two) to measure water potential over the range -30 to -600 kPa, and one TCAV thermocouple probe to record soil temperature. At each depth the time domain reflectometry and gypsum blocks were separated laterally by 1m. The pit was backfilled by hand, layer by layer, to the original bulk density. Sieved soil was packed around each probe to ensure good contact and a layer of rock-free soil of at least 3cm around the sensors. Data from the gypsum blocks was recorded by a Measurement Engineering Australia SDI12 logger and data from the time domain reflectometry and temperature probes was recorded by a Campbell Scientific logger. Recordings were taken every hour from August 2007 (except for

water potential, for which reliable readings commenced in July 2008) until June 2010. Results presented are based on mean values for each depth.

Water uptake was calculated using changes in soil water content. The soil water content measured at each depth was assumed to represent that of a 0.2m depth increment with the probe at the centre, i.e. 0-0.2, 0.65-0.85 and 1.4-1.6m depth layers. Soil water content of the intermediate layers was estimated as being midway between the layers above and below. The distribution of soil water with depth was described using the slope of the linear regression of water potential or water content against depth for the three measured depths. Water content of the whole profile (0-1.6m) was calculated as the sum of water in all five layers, corrected for the volumetric proportion of rock. During rain-free periods there was a distinct diurnal pattern of soil water content fluctuation, with water content decreasing rapidly during daylight hours and more slowly during the night. The rate of water content change and the amplitude of the diurnal fluctuations decreased with depth (Figure 19). It was assumed that uptake occurs during daylight hours only, as shown by sap flow measurements in a similar forest (McJannet *et al.* 2007). Thus daily uptake was calculated as the decrease in the amount of water held in the soil profile between 6:00am and 6:00pm, minus the amount lost by drainage during that period. The amount lost by drainage was estimated as the average of the decrease in the amount of water held in the soil profile in the preceding and succeeding twelve-hour periods. Daily water uptake was calculated only for days in which there was <1mm of rain in the period from 6:00pm the previous day until 6:00am on the following day. The relationship between uptake and other factors was examined by correlation and regression. Annual uptake was estimated by adding measured daily uptake values. Uptake during rainy periods was estimated from the model described in the results. Results for 2007-2008 were not used, to allow time for roots to re-establish themselves in the back-filled pit.

Three bores were installed to monitor groundwater depth and calculate uptake from groundwater. The bores were drilled in May 2008, as close as possible to the soil water monitoring site (Figure 18). Bore 1 had soil and rocks at 0-13m and solid rock at 13-14m, where drilling stopped. Bore 2 had soil and rocks at 0-33m and solid rock at 33-34m, where drilling stopped. Bore 3 had soil and rocks at 0-14m, where drilling stopped. Depth loggers were installed in bores 1 and 2 in July 2008. Depth loggers were installed in bores 1 and 2 in July 2008.

Weather data was collected using an Envirodata (Weather Master 2000) automatic recording station situated in an open area close to the soil monitoring site (Figure 18).  $ET_0$  was calculated using the modified Penman equation (Doorenbos and Pruitt 1977).

## Results

Most of the fertility is in the topsoil, due to its high organic matter content. Acidity increases and nutrient holding capacity decreases rapidly with depth. Soil texture is loam (18% clay) at the surface and heaviest (38% clay) at 0.4-0.6m depth (Table 4). Organic matter content was surprisingly constant to 0.2m depth, suggesting that there has been soil mixing. The volumetric proportion of rock was 32% near the surface and around 44% below 0.2m depth.

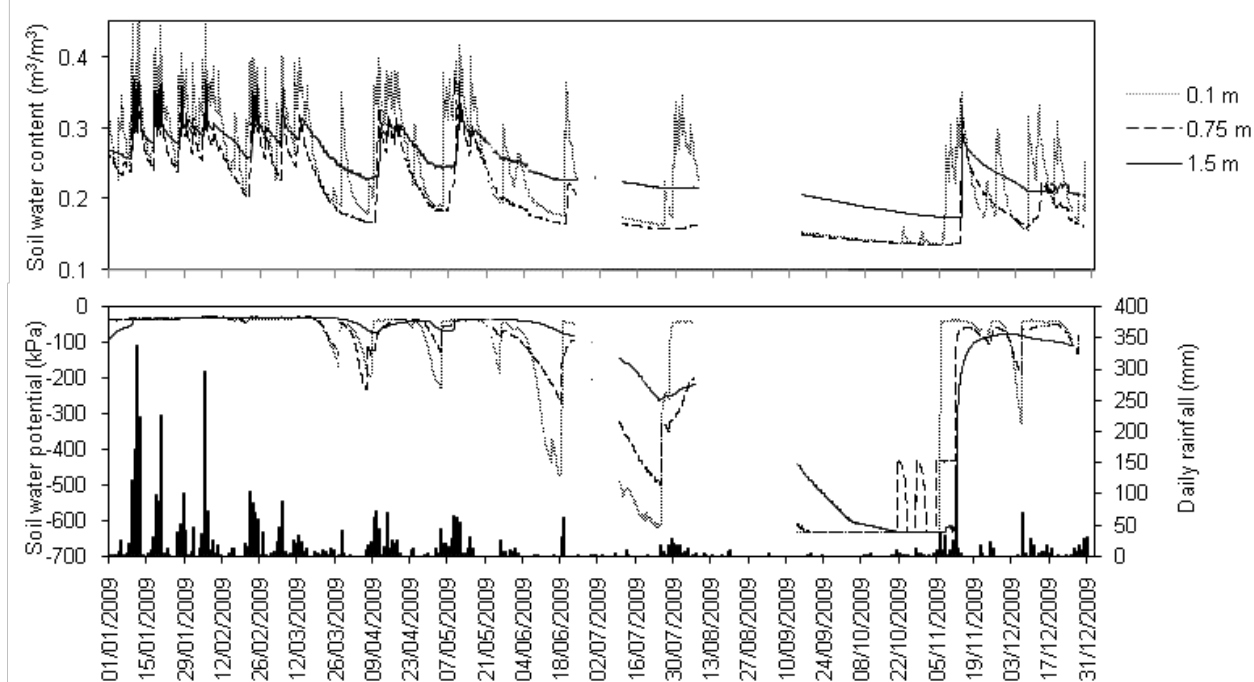
Rainfall, soil water content and soil water potential for the 2009 calendar year are shown in Figure 18. Rainfall and soil water contents were high for the first four months of the year. Over the course of the dry season soil moisture was steadily depleted at all depths, with occasional rainfall not being adequate to recharge the profile. In September and October there was virtually no rain and soil water content declined to the lowest level recorded during the project. The response of soil water content was rapid near the surface and dampened with depth. At no depth did the soil reach saturation for any significant length of time.

**Table 4:** Soil chemical properties in the pit.

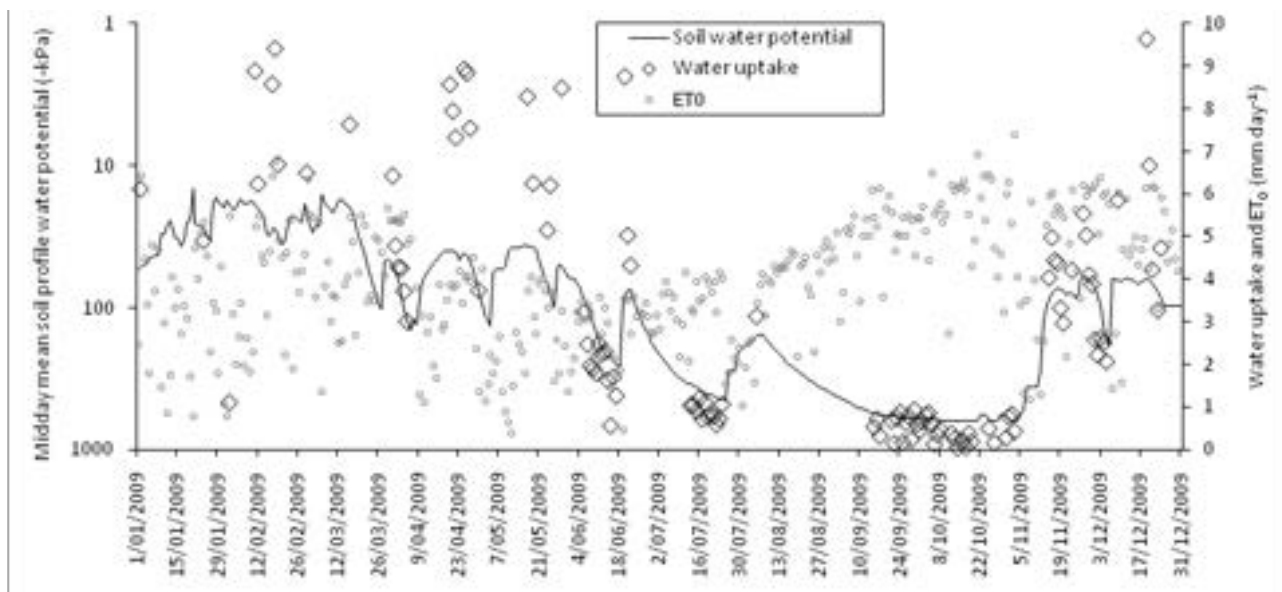
| Depth     | Clay | pH  | EC   | Org. C | Col. P | Ca       | Mg   | Na   | K    | Acid | ECEC |
|-----------|------|-----|------|--------|--------|----------|------|------|------|------|------|
| M         | %    |     | dS/m | %      | mg/kg  | cmolc/kg |      |      |      |      |      |
| 0.0-0.1   | 18   | 5.1 | 0.35 | 7.84   | 36     | 8.76     | 2.08 | 0.32 | 0.58 | 0.29 | 11.8 |
| 0.1-0.2   | 21   | 5.5 | 0.26 | 7.89   | 26     | 14.20    | 1.88 | 0.27 | 0.47 | 0.14 | 16.8 |
| 0.2-0.4   | 29   | 5.4 | 0.16 | 3.50   | 15     | 6.27     | 0.63 | 0.15 | 0.32 | 0.17 | 7.4  |
| 0.4-0.6   | 38   | 5.0 | 0.04 | 1.06   | 7      | 1.28     | 0.19 | 0.10 | 0.11 | 0.89 | 2.5  |
| 0.6-0.8   | 33   | 5.1 | 0.02 | 0.54   | 24     | 0.49     | 0.23 | 0.12 | 0.13 | 0.94 | 1.8  |
| 1.45-1.55 | 25   | 4.7 | 0.01 | 0.30   | 4      | 0.16     | 0.28 | 0.09 | 0.14 | 1.28 | 1.9  |

Throughout the study period watertable level was at 10.0-13.0m below ground in bore 1 and 9.9-10.2m below ground in bore 2. There was no discernible diurnal fluctuation in watertable level, so there was little or no uptake of water from the watertable.

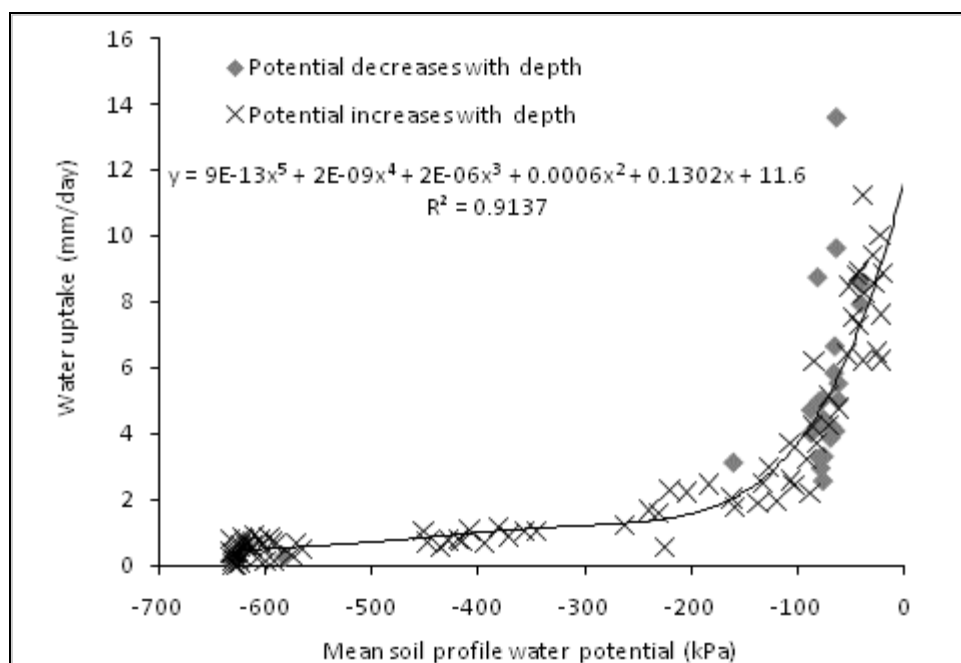
Uptake was related to supply of water rather than atmospheric demand. Potential evapotranspiration ( $ET_0$ ) was very variable during the wet season and then became less variable and higher towards the end of the dry season (Figure 19). There was little correspondence between  $ET_0$  and uptake, with uptake often being higher than  $ET_0$  in the wet season and lower in the dry season (Figure 19). Actual ET could be expected to be lower than  $ET_0$  throughout the year and especially at high levels of  $ET_0$  (McJannet *et al.* 2007). Uptake was closely related to the availability of water in the soil profile, and the relationship was best expressed using the average water potential of the profile (Figure 20). There appeared to be threshold value of water potential, around -100 kPa, above which uptake rose rapidly. When mean water potential was high, uptake was quite variable and appeared to be partially influenced by the distribution of water in the profile (Figure 20).



**Figure 18:** Soil water content (a), soil water potential and rainfall (b) during the year. The two gaps in soil water content and potential measurements are due to battery failure.



**Figure 19:** Average soil profile water potential,  $ET_0$  and uptake. The gaps in water potential were interpolated using a linear function as there was no significant rain during those periods.



**Figure 20:** Relationship between water uptake and mean soil profile water potential.

## Discussion

Total estimated uptake for the year was high, close to total  $ET_0$ , which seems unlikely as over the course of a year uptake could be expected to equal  $ET$ . There are reasons why the estimate produced here could either be an overestimate or an underestimate. Firstly, the calculations here take no account of uptake from depths greater than 1.6m. However, low diurnal fluctuations in water content at 1.5m depth suggest that uptake from below this depth were low. Secondly, the method used here assumed no uptake during the night. If there is uptake during the night, then the uptake rates presented here would be an underestimate.

The forest evidently relies on high uptake of water during wet periods to help it maintain  $ET$  during periods of high evaporative demand and low supply. As trees are not obtaining sufficient water in the dry season to supply the transpiration demand, any increase in the length or severity of the dry season is likely to have significant effects on forest ecology.

In conclusion, temporal variations in water uptake are controlled by availability of water rather than by the factors that control  $ET$ . Trees accumulate water when there is ample supply and lose it in times of water deficit.

## Part (ii) Below-ground fluxes and transformations of carbon

### Introduction

The forest carbon cycle involves, (a) conversion of carbon dioxide into organic compounds in photosynthesis, (b) conversion of the organic C back to carbon dioxide via plant respiration, (c) transfer of organic C to the soil via litter fall, root exudation and root death, (d) cycling of organic C between soil organic matter and soil organisms, and (e) conversion of organic C to carbon dioxide by microbial and faunal respiration. Carbon dioxide fluxes between the atmosphere and forest were studied at the canopy level using eddy covariance (Objective a). In this part of the work the carbon fluxes through the soil were studied.

### Activities

#### *Grid soil surveys*

In February 2007 a soil survey was carried out across the site. Measurement/sampling sites were adjacent to the 25 litter traps, which corresponded to a grid of 25 points, on a 5x5 square arrangement, with each point 25m apart, giving a total survey area of 100m x 100m, centred on the crane base. At each point, one sample was taken from the 0-0.1m depth layer, as close to the litter trap as possible. The samples were air-dried, sieved to <2mm and analysed according to the methods described in part A of this report. Every second sample was analysed for particle size distribution.

The ratio of rock:soil at each point on the grid was estimated using measurements of apparent electrical conductivity ( $E_{Ca}$ , approximately 2-3m from the traps, in no particular direction), made using electromagnetic (EM) meters. Apparent electrical conductivity is a function of soil salt, water and clay content, in decreasing order of importance. In this environment there is so little salt that we can ignore its contribution to  $E_{Ca}$ . The main feature of the soils is their very high content of gravel and boulders. We expect soil to have a higher EC than rock, due to higher water and clay content. Therefore, in this environment, we expect  $E_{Ca}$  to be a measure of the proportion of soil vs. rock in the measured volume. Two EM meters were used (EM38 and EM31), each in two modes (H and V), to measure  $E_{Ca}$  to four different depths. The depth of influence is impossible to specify exactly, as it depends on the magnitude and depth distribution of EC. However, depths of influence are usually assumed to be approximately 0.8m (EM38-H), 1.5m (EM38-V), 2m (EM31-H) and 4m (EM31-V). The EM readings were calibrated using measurements of rock:soil ratio made in

three pits. One pit, and the methods used to measure rock:soil ratio, are described in part A. The additional pits were dug by a backhoe at litter trap 3 (low EM31 reading) and litter trap 18 (high EM31 reading).

Canopy openness was measured at all grid points using a Skye 660/730nm Ratio Sensor (SKR 110) and meter (SKR 100). It measures the red:far red ratio, which is highly correlated with leaf area index and percent canopy transmittance under overcast conditions (Capers and Chazdon 2004).

Soil water content was measured at all grid points using a Campbell 615 reflectometer with HydroSense™ reader. It measures volumetric water content of the 0-0.3m depth layer. Soil water content was then also measured gravimetrically.

The 5x5 grid survey of ECa appeared promising as a way of estimating soil:rock proportions, but the resolution of the survey was rather coarse. We therefore marked out a new square 9x9 grid over the same area, at 12.5m spacing. At each point on the grid apparent electrical conductivity was measured using EM38 and EM31 probes and soil water content was measured using capacitance probes.

### ***Turnover of organic C***

Turnover rates of litter C in the soil were calculated using the litter fall data reported elsewhere and soil C contents to 1.5m depth.

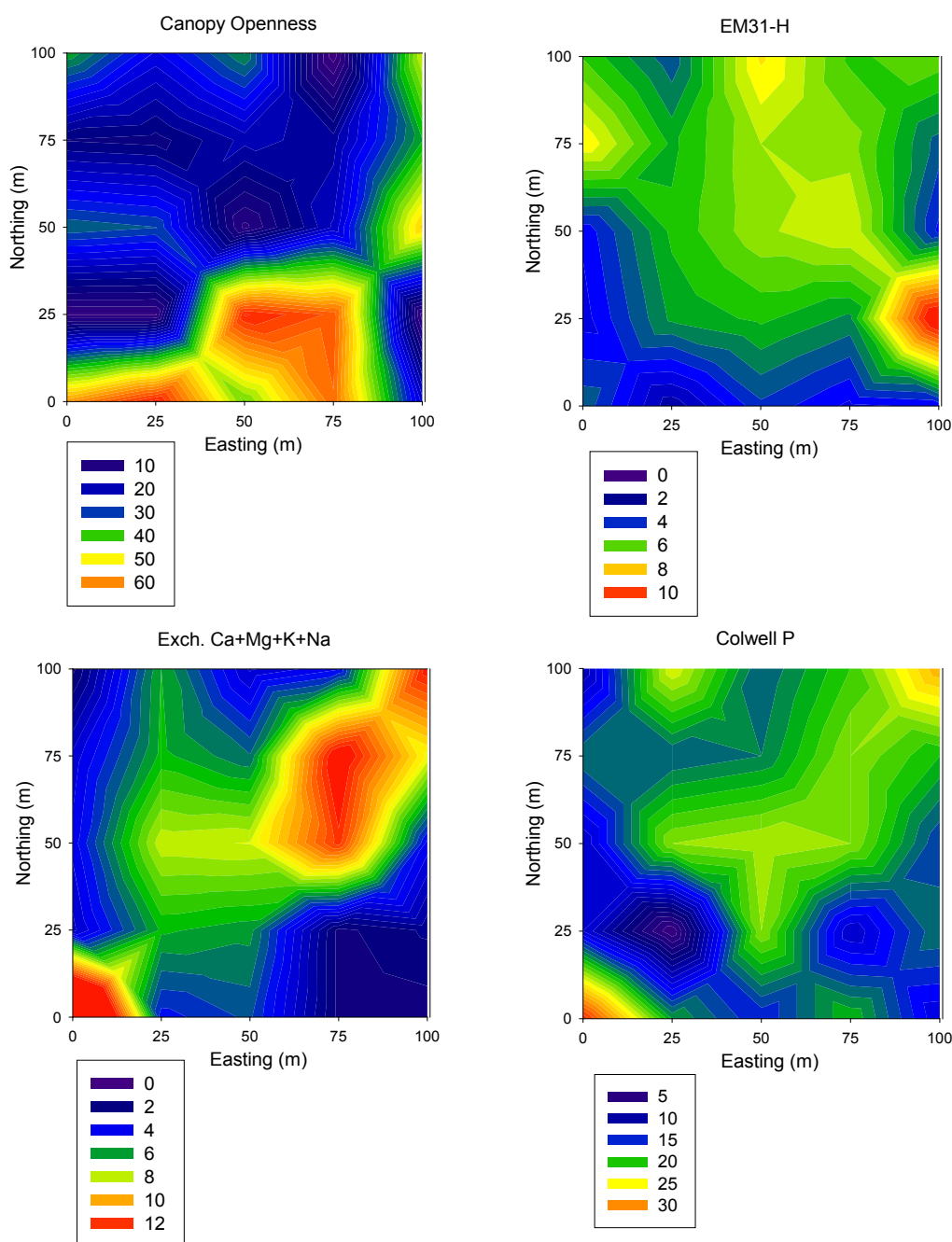
The nature of organic carbon compounds in litter and soil were characterized using elemental analysis and <sup>13</sup>C nuclear magnetic resonance (NMR), using the method described by Nelson and Baldock (2005) with some modifications. The modifications included fitting the modeled and actual distribution of signal intensity using a least squares minimisation process, and using a different spectral distribution for the charcoal component (from Knicker 2007).

The effect of litter fall on soil respiration was measured by manipulating litter input rates. The litter manipulation experiment had three rates of litter addition over a period of four months (natural, removed, and additional litter supplied) and is described in more detail in the 'Objective e' section of this report (page 37). Respiration rates were measured using static chambers and carbon dioxide analysis by gas chromatography. Measurements were made using one chamber in each of the 6 replicate plots. Carbon content of the 0-5cm depth layer was measured.

## **Results**

### ***Grid soil surveys***

The topsoil over most of the site is reasonably fertile, with moderate to high levels of available P, K, Ca and Mg (Table c1). Topsoil fertility was greatest in a zone extending from the centre to the NE corner of the site (Figure 21). Soil organic matter content is largely responsible for soil fertility at this site, with contents of phosphorus and exchangeable cations significantly correlated with organic C content in the topsoils and decreasing with depth (Table 4). It also appeared that soil:rock proportion varied across the site, with the rockiest area being along the southern margin (Figure 19). However, the subsequent, higher resolution, survey showed that rockiness was fairly random over the site. Canopy cover was related to soil properties, being highest in areas where soil was not rocky (EM31-H >6 mS/m), exchangeable non-acid cation content was high (>6 cmolc/kg) and exchangeable acidity was low (<1 cmolc/kg). One area had high canopy cover but did not fit those soil criteria; it however had unusually high water content, perhaps due to runoff from adjacent areas.

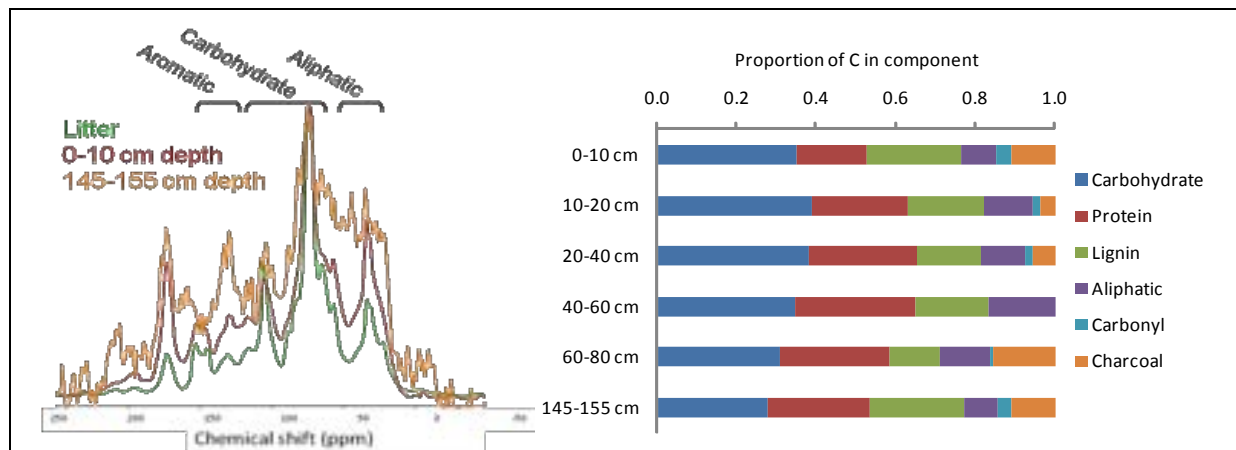


**Figure 21:** Canopy openness (%) soil ECa (mS/m, EM31-H), exchangeable cation (cmolc/kg) and available P (mg/kg) content of soil (0-0.1 m depth) across the site. The survey is centred on the canopy crane base.

### Carbon turnover

The amount of soil organic C to 1.5m depth was calculated as  $23.6\text{kg/m}^2$ . That value compares to above ground biomass storage of C of approximately  $15\text{kg/m}^2$  (300t dry matter/ha with C content of 50%). Given an annual litter input of 11.0-12.4 t/ha (reported elsewhere), and assuming a litter C content of 50%, this equates to an annual input of C as litter of  $0.585\text{kg/m}^2$ , and a turnover rate through the soil of 2.5% per year. If root inputs are assumed to be equal to litter inputs, then the turnover rate for soil C becomes 5.0% per year.

Soil organic matter was composed mostly of carbohydrate, protein, lignin and aliphatic material, in decreasing order of abundance. With depth, below 20cm, there was a decrease in carbohydrate C relative to all other components of soil organic matter (Figure 22). The litter manipulation experiment showed that there were no significant effects of litter addition rate on soil carbon content of respiration rate.



**Figure 22:**  $^{13}\text{C}$  NMR spectra of litter, topsoil and subsoil (HF-treated), normalised to the height of the largest (carbohydrate) peak, and bar chart showing the proportion of molecular components of the soil organic matter.

## Discussion

The relationship between canopy openness and soil depth and fertility suggests that spatial variations in photosynthesis (and thus C inputs to the soil) and transpiration are influenced by soil properties. The shallowness of the high organic matter/high fertility topsoil means that carbon cycling is likely to be sensitive to perturbations in rainfall. However, changes to litter inputs over a four-month period had no effect on respiration, so soil respiration is dominated by older C and hence changes in carbon cycling will only be detectable at longer time scales. The small amount of organic matter at depth was not much different in composition to shallower organic matter, suggesting that turnover rates are similar throughout the profile.

In conclusion, turnover of carbon on and below the soil surface of the forest is rapid and likely to be sensitive to changes in net primary productivity.

## Acknowledgements

We are grateful to Steve Turton and Earthwatch volunteers for carrying out the soil sampling in February 2007.

For the EM survey carried out in December 2007, we are grateful to Rodney Cooper, Isha Segboer, Kalu Davies, Melinda Greenfield for doing the field work, the Department of Natural Resources and Water, Mareeba, for use of their EM31, Bureau of Sugar Experiment Stations, Brandon, for use of their EM38 and Steven Turton and Catherine Pohlman for use of their Skye ratio sensor and meter.

## Objective (d) – Flowering/fruiting Phenology

**Principal Investigator: Dr Caroline Gross, University of New England**

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### Introduction

Phenology is the scientific study of periodic biological phenomena, such as flowering and fruiting episodes. The triggers for flowering episodes are many but include abiotic factors (e.g. moisture levels, particularly moisture stress, day-length, temperature) and biotic factors (e.g. phylogeny constraints, co-evolution with pollinators and fruit dispersers, facilitation, competition). Flowering episodes and successful pollination are thus susceptible to a wide range of perturbations and changes to climate could directly or indirectly influence flowering and fruiting phenology (Boulter *et.al.* 2006, Johnson 1992). The latter two phenophases exhibit strong timing-sensitive relationships with pollinators, seed dispersers and herbivores (Wright, 1996, Waser 1979, Mosquin, 1971) and therefore shifts in these events can create a cascade of effects throughout the ecosystem.

In particular abiotic factors such as temperature, photoperiod and rainfall have been evidently linked to phenological episodes (Brearley *et.al.* 2007, Molau *et.al.* 2005). Therefore understanding plant responses to natural, interannual climate variation will be crucial to understanding the sensitivity of lowland rainforests to climate change.

Evidence is accruing that components of flowering (e.g. the point of peak flowering, the volume of flowers) is shifting with changes in climate (Miller-Rushing and Inouye 2009). The biological ramifications of this are significant and in particular for the sustenance of mutualists and the production of viable seed. However, the detection of changes in flowering phenology could well be a 'hit and miss' situation with a single species approach. Instead, the response of an entire plant community to climate change is likely to provide a more robust account of any shifts in flowering against changes in abiotic variables (e.g. temperature changes). Here we report on seventeen months of investigation of flowering and fruiting phenology for two lowland rainforest communities (50+ species) in the wet tropics of Australia.

Climate predictions suggest that annual temperatures across the Wet Tropic region will increase by around 4°C by the year 2085 (MTSRF Project 2.5ii.1, 2010) and that the climate will become substantially drier in the wet season. Thus, we anticipate that we will detect a sensitivity of lowland rainforests to climate change through observing canopy level reproductive processes.

Currently, historical phenological monitoring of flora within Australia is very limited thus this project will create one of Australia's largest phenological data sets and form a major stepping stone towards enhancing our knowledge and awareness of the effects climate change will have on the tropical rainforests of Australia. The project aims to monitor phenological events in specific plant species which are likely to be early indicators of climate change influence on the lowland rainforest in the Cairns region and to further determine if individual species show greater sensitivity to climate fluctuations therefore having a greater chance of extinction. Outcomes will be relevant to a range of users including other research scientists, land managers, conservationists and the tourism industry.

### Objectives

Our objectives are to, (1) determine the medium-term relationship between flowering and fruiting phenology and climatic variables in lowland rainforest tree communities in northern Australia, and (2) to test the hypothesis that climate change is changing flowering and fruiting behaviour.

## Activities

Two lowland sites were chosen for the phenology investigation.

The Australian Canopy Crane Research Facility (ACCRF) site is located at Cape Tribulation. The forest is complex mesophyll vine forest, it was damaged by Cyclone *Rona* in 1999 but has recovered significantly in the subsequent years. The sample site is a 1Ha vegetation census plot with access to the canopy provided by the gondola of a construction crane.

The SkyRail transect begins in Smithfield at 25m elevation and ascends to over 400m elevation ending in Kuranda. The entire cable way covers an area of 7.5km of simple-complex mesophyll to notophyll vine forest and consists of 36 towers. Below Tower 7, this section of forest has been disturbed by past logging and road ways and in parts consists of *Eucalyptus leptophleba*, *Corymbia clarksoniana* and *E. platyphylla* open-forest to woodland, thus digital imagery collection begins after Tower 7. The transect ends at the Barron River as beyond this point, the forest is replanted and species which are not native of the area have been included. Therefore, the length of the phenological transect is approximately 5km, thus digital imagery collection begins after Tower 7.

Flowering and fruiting phenology is scored by recording the onset, peak and duration of events at an individual plant level. Access to the flora at the two study sites is via a direct (canopy crane) or indirect method (SkyRail).

In the **direct method**, canopies at the crane site are visually 'swept' every month and new records of flowering and fruiting are recorded against tagged trees. There is no immediate restriction on time and flowering and fruiting samples can be collected directly. The documentation of flowering phenologies for 57 tree species growing under the span of the Cape Tribulation Canopy Crane was commenced in January 2009. In this way a flowering spectrum has been built at the individual, species and community level (see below).

In the **indirect method**, digital imagery is taken of canopies observed from a fast moving gondola on the SkyRail pathway near Cairns. The pathway is 5km long and digital imagery is collected monthly. The development of the technique for gathering digital phenological data from tree canopies using the unique access presented by the gondola of the SkyRail was quite challenging but has been successful in capturing replicate photographs of individual trees across months (Figure 23). Digital images are captured using a Sony DSLR  $\alpha$ -700P and stored as 12MP images. 1300-1500 photographs are recorded each month and can be stitched together to form a transect of readable images (Figure 23).

The imagery is checked *post-hoc* when flowering and fruiting events are allocated to a species and relative geographic position along the 5km transect. This is a labour intensive method and requires verification of data at several levels especially species identification as there is no direct access to the canopy for sample collection. In addition the techniques for 'stitching' imagery have proved problematic and new methodologies for handling the digital imagery have had to be devised.

In year six, phenology data are combined with climate data to determine (e.g. via regression analyses) whether there are intra- and inter annual variations in phenology that are correlated with climatic variables. *A priori* we expect to see differences in phenology (e.g. onset of flowering) between the two study sites but, as there are many plant taxa in common between the two locations, we will be able to test the hypothesis that climate changes affects flowering and fruiting phenologies in a substantive manner. This project then is a long term study extending over a minimum of six years and therefore it still in the very early stages with data collection only beginning in January 2009 at both the Canopy Crane site and SkyRail.



**Figure 23:** Flowering and fruiting phenological spectrum for 57 tree species at Cape Tribulation, north Queensland, Australia.

The species lists are provisional for both locations as vouchering of specimens is yet to be completed. Currently voucher collection at the Canopy Crane site is underway, with 152 specimens accumulated thus far. There is a moderate level of overlap in species composition between the two sites which will allow for latitudinal comparisons (82 species at Crane, 107 species at SkyRail, 19 species in common). Climatic information for the same phenological periods is being captured. At the Crane site there has been an All Weather Station (AWS) in operation since September 1998. At SkyRail the site operators have had low accuracy rain, temperature and relative humidity measurements on-going for a considerable period at two of the stations (Red Peak, Barron Falls). We are currently arranging for the installation of two AWS at these sites so that this data set can be augmented with more accurate data.

These climatic data will be used in time to look at the significance of phenological patterns against any changes on climate. To this end the team has been very fortunate to receive in-kind observational data from SkyRail covering periods from 1996 to the present. Two workers at SkyRail collected phenological data in the 1990s using visual identification and we have been offered access to the phenology data collected by Mr Tore Lien Linde (see below). This will enable a ten-year phenological spectrum to be built that will greatly assist with establishing baseline conditions. The data re covering 211 species (SkyRail, unpub data) and are proving to be most informative.

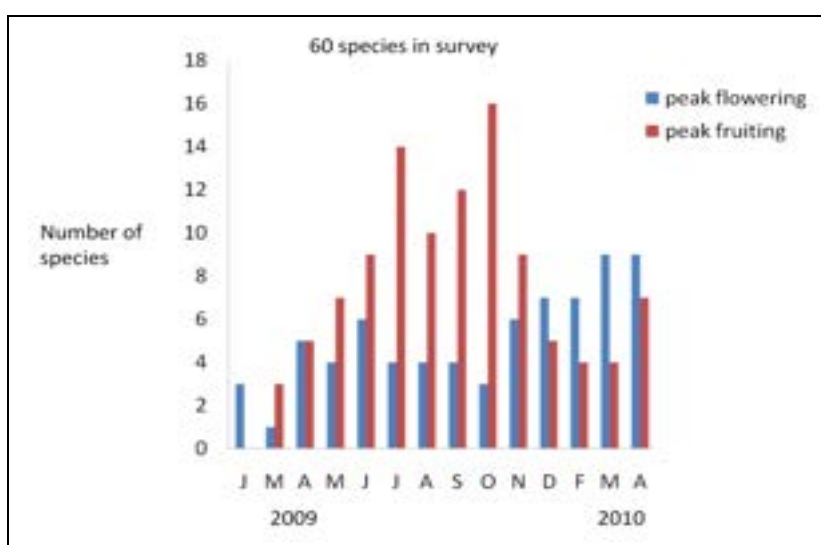
### Constraints

The constraints of the outlined approach rest primarily with the problem of poor site replication (ideally three lowland sites comprised of the same vegetation type at each of

Cape Tribulation and near Cairns should be employed). None the less, flowering properties (e.g. onset of flowering, peak flowering, duration) will be able to be regressed against abiotic variables (e.g. temperature, humidity, CO<sub>2</sub> concentrations) collected locally. Power in the analyses comes from investigating many species simultaneously.

## Results and discussion

The work is ongoing and cannot be interrogated for temporal shifts in phenology until at least 72 months of phenological and climatic data have been collected. However, based on seventeen months' data from the Crane Site a phenological spectrum is emerging (Figure 24). Results so far show that there is a degree of inter-annual variation in flowering within the tree community at the Crane Site. More species co-fruit (16 species in October 2009) than co-flower (8 species in April 2010) – a result of the greater developmental times for fruits compared with flowers.

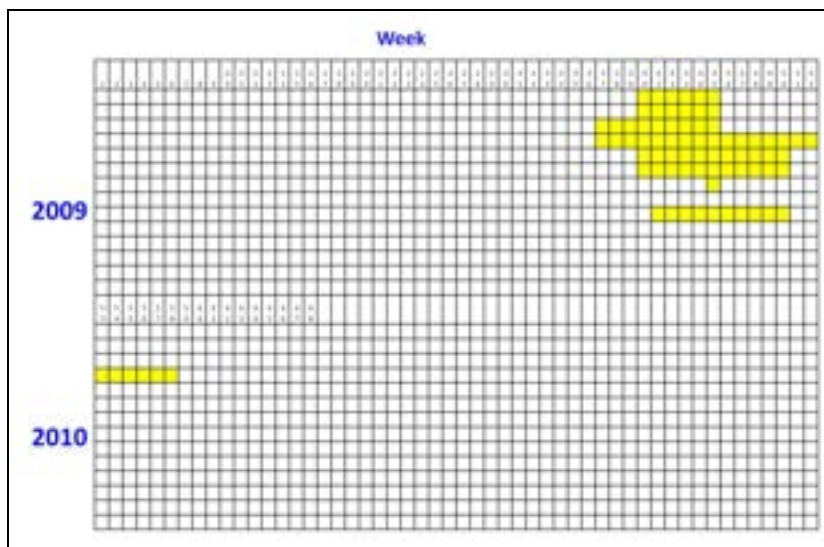


**Figure 24:** Flowering and fruiting phenological spectrum for 57 tree species at Cape Tribulation, north Queensland, Australia.

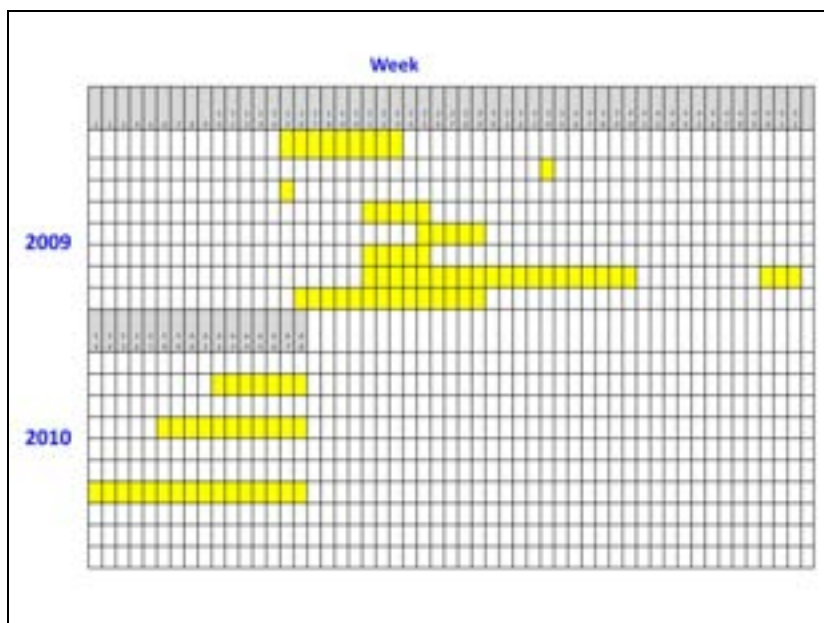
At Cape Tribulation, and within species, patterns are emerging of inter and intra-species variability. *Cardwellia sublimis* for example (a common and likely key stone species for pollinators) has a conserved within-species spectrum (Figure 25). Most individuals co-flowered. Whereas *Acmena graveolens* (Figure 26), has more variation in onset and overlap among individuals

Preliminary analysis of the historical data for SkyRail is underway. Data for *Cardwellia sublimis* for example (Figure 27) shows a species with a rhythmic late dry season-early wet season flowering phenology.

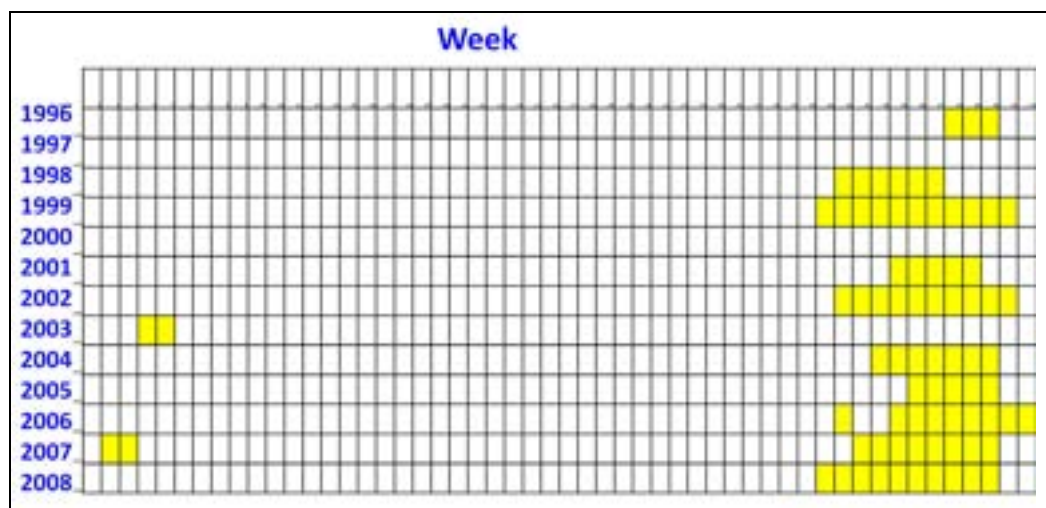
This pattern is similar to the first seasons of data gathered for *Cardwellia sublimis* at the Canopy Crane site (Figure 25). Data for *Argyrodendron peralatum* for 1996-2008 for the SkyRail transect shows a long flowering season that shows a high degree of rhythm among years which is not dissimilar to data for this species at the Crane site (one year only 2009) (Figure 28).



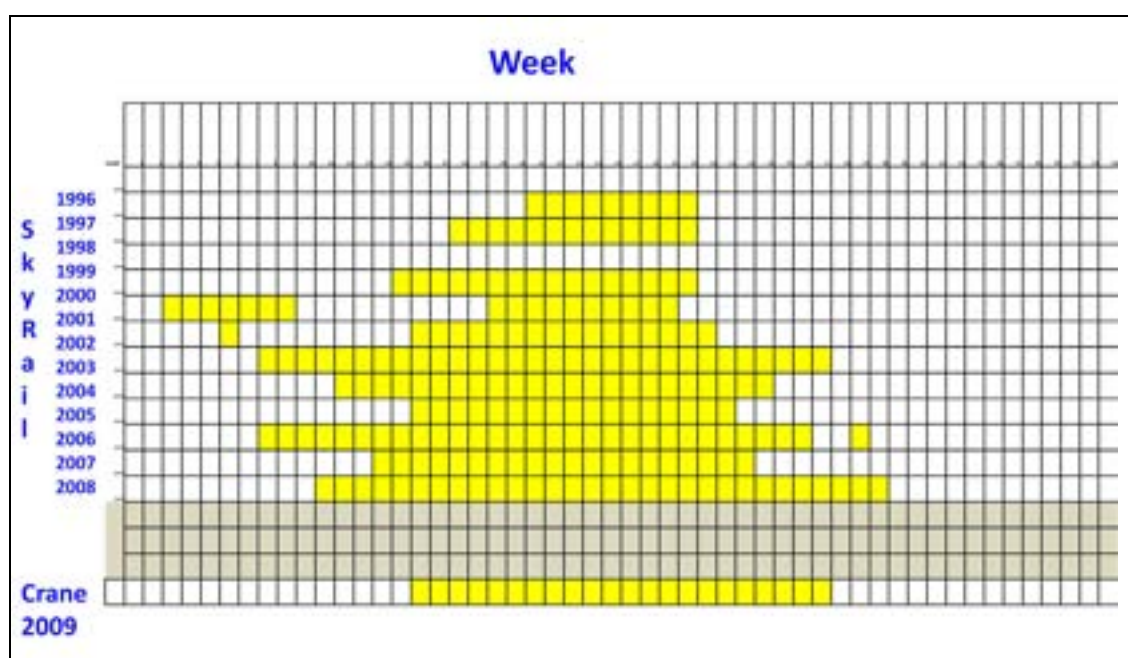
**Figure 25:** Flowering phenology for *Cardwellia sublimis* from the Canopy Crane site, Cape Tribulation, north Queensland. Within each of two years (2009 and 2010) each row represents an individual tree ( $n = 12$  trees) and each cell a week. Yellow boxes are census dates where the individual was in flower (weeks 1-52).



**Figure 26:** Sixteen months' flowering data for eight individuals of *Acmena graveolens* from the Canopy Crane site, Cape Tribulation, north Queensland. Within each of two years (2009 and 2010) each row represents an individual tree ( $n = 8$  trees) and each cell a week. Yellow boxes are census dates where the individual was in flower (weeks 1-52).



**Figure 27:** Flowering data for *Cardwellia sublimis* (n = 79 trees) from the SkyRail transect 1996-2008. Yellow boxes are census dates where the population was in flower (weeks 1-52).



**Figure 28:** Flowering phenology for *Argirodendron peralatum* at SkyRail (1996-2008) (n = 57 trees) and at the Crane Site (2009, n = 6 trees). Yellow boxes are census dates where the population was in flower (weeks 1-52).

The analysis of the digital images taken at Skyrail has proved to be more complicated than expected. Data analysis can only commence when the trees are identified correctly. We had initially assumed that the trees would be labelled into a spreadsheet and then Bob Jago (Cairns City Council) would identify them. Once the number of images became apparent per transect (1300-1500) this method was ruled out. As Tore Linde has detailed knowledge of the trees within the Skyrail transect, he has been sourced to help with the identification. The approach developed has been to identify singular flowering or fruiting events in individual photographs (Figure 29) and label the tree with a position code. This data is stored in an

Excel database and in the future the individual identified trees will be transcribed onto a 'stitched transect' (Figure 23).

The correct identification often relies on the presence of flowers or fruits and so the development of the transect database will be a work in progress for many years. Once an individual tree is identified in the database the entry is then checked by Bob Jago. Subsequent to this all species will have voucher specimens collected and deposited at the Cairns Herbarium.

## Summary

Within two years of the project commencing the team has established methods for documenting flowering and fruiting phenologies for more than 100 species over two lowland rainforest canopy terrains. A very large amount of imagery and census records are being accrued and the team has established protocols for data acquisition, storage and qualitative analysis techniques for the unique data set that is being accrued. Publications are planned once climatic data can be combined with the phenological data.



**Figure 29:** Canopy image of *Flindersia afflaiana* (bottom right hand corner) with annotations as to phenological state, date and transect.

## **Objective (e) – Resource related fluctuations in insect populations**

### **Principal Investigator: Prof Nigel Stork, University of Melbourne**

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#### **Introduction**

The majority of species on Earth are thought to be rainforest insects (Hamilton *et al.* 2010) and they make massive contributions to ecosystem functioning through their involvement in processes such as pollination, herbivory and decomposition. Of these three ecological processes, the role that insects play in decomposition is the least well known (Kitching 2006). Most leaves from plants remain uneaten while still on trees. However, when shed, these leaves contain many important nutrients that need to be retained in ecosystems for plants to re-use. The breakdown of dead leaves is primarily driven by microorganisms, interacting with invertebrates including insects (Hattenschwiler *et al.* 2005). Thus insects inhabiting and assisting decomposition of leaf litter on the ground ultimately affects plant productivity.

Predicting what will be the effects of climate change on these plant-insect interactions is an important ecological question. To make such predictions we need to know the factors that influence the variation in species and numbers of decomposer insects. Total litter volume and nutritional content appears to be important (Kaspari and Yanoviak 2009). Climate could also be important as a previous study at the crane site showed that beetles show distinct seasonality that may be correlated with climatic variability (Grimbacher and Stork 2009). However, disentangling the effect of seasonality of climate from seasonality of resources requires careful experimentation (Grimbacher and Stork 2009). Guided by our previous study, we set out to determine whether insect biodiversity is driven by seasonality of climate and/ or seasonality of resources. To do this we conducted two experiments on beetles and used the results to predict how climate change may influence insect biodiversity.

#### **Activities**

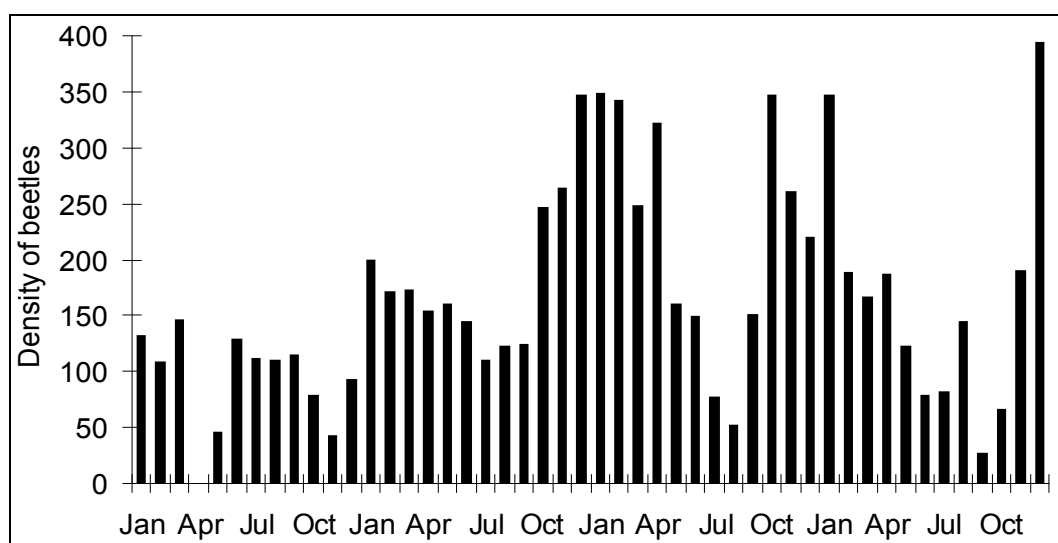
Sampling of insects inhabiting leaf litter was initiated in January 2006 and finished in December 2009. Sampling involved a monthly collection of five litres of finely sifted leaf-litter, collected from the ground at the crane site. This material was then run through Tullgren funnels for approximately twelve hours to extract insects, from which the beetles were removed, counted and stored in ethanol. Following the microhabitat sampling, beetle specimens were processed (removed from samples) and dry-mounted ahead of species identification. This process is very tedious and time consuming but it is essential for species-level identification. Analyses have been conducted on fluctuations in overall beetle numbers and how these relate to fluctuations in climate.

A leaf litter manipulation experiment was initiated in September 2008 to investigate how the amount of leaf litter on the ground influences beetle abundance. Three treatments were tested among six replicate 3X3m plots. Leaf litter was excluded from plots with bird netting (mesh size 2X2 cm) suspended 100-50cm above the ground (exclusion treatment). Each of the leaf litter addition plots (addition treatment) received a monthly addition of sixty litres of sifted (to remove invertebrates) leaf litter collected nearby. Control plots were marked out but otherwise unaltered. The experiment was completed in early February 2009 when the leaf litter from each plot was collected and the insects inhabiting the leaf litter were extracted with Tullgren funnels.

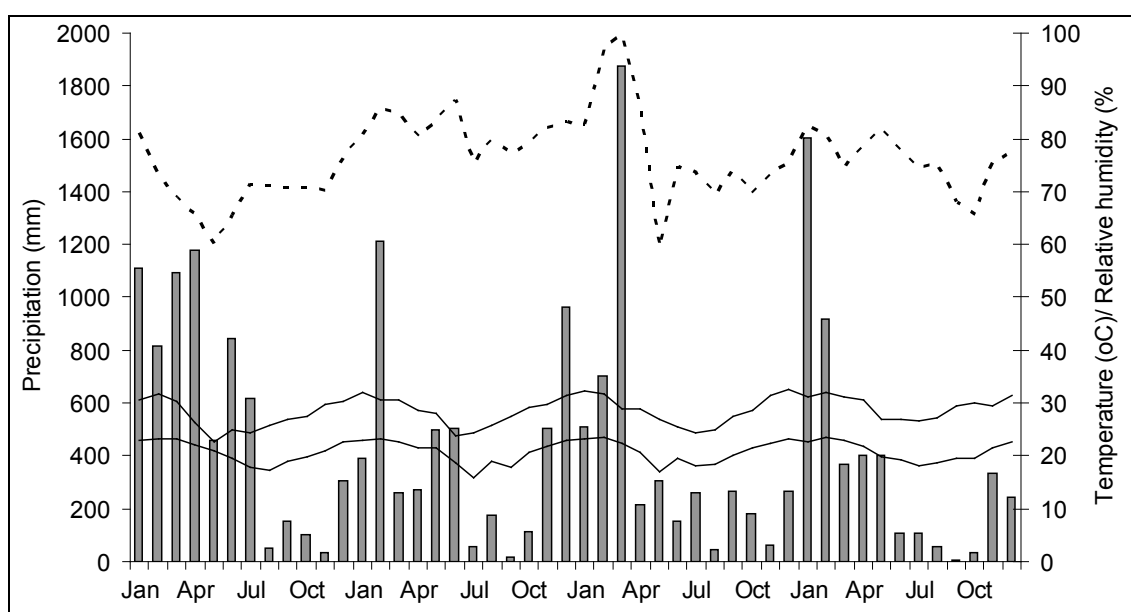
#### **Results and discussion**

The monthly beetle collecting time series captured 7909 beetles (January 2006 to December 2009). For this experiment a standard volume of fine leaf litter (five litres) was collected from the ground under the circumference of the canopy crane at Cape Tribulation. Standardising the volume of leaf litter, allows temporal variation in insect density to be considered

independent of seasonal variations in leaf litter fall and volume (see Objective b). This time series (Figure 30) shows both seasonal and yearly variation in beetle density. Climatic variables also show seasonal variation (Figure 31).



**Figure 30:** Temporal variation in the density of beetles extracted from monthly collections of leaf litter (five litres) from the ground at the Canopy Crane Research Facility, Cape Tribulation.



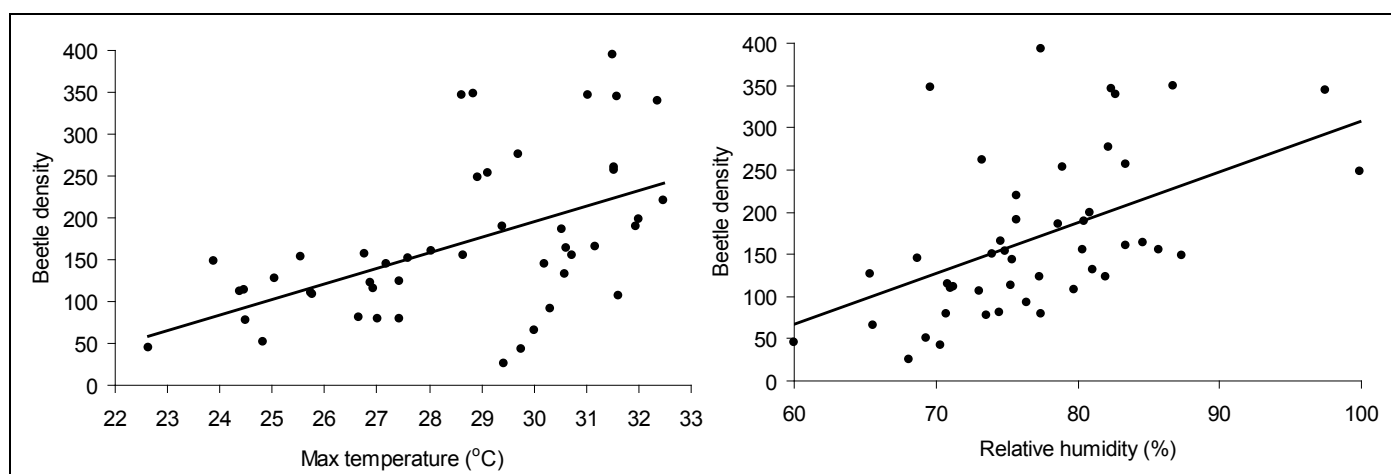
**Figure 31:** Total monthly precipitation (bars), mean daily minimum and maximum temperature (solid lines) and mean daily relative humidity (dashed line) for the Canopy Crane Research Facility, Cape Tribulation between January 2006 and December 2009.

When the monthly beetle density counts were tested with simple linear regression against climatic data, measures of temperature and relative humidity were positively correlated (Table 5). Solar radiation, evaporation and total monthly rainfall were not significantly correlated with monthly beetle density counts (Table 5). It is particularly interesting that there

was a positive linear relationship between beetle density and temperature and relative humidity (Figure 32), although the variation in beetle density explained by these climatic variables was only 29%. Taking all climatic variables (including one temperature measure – the maximum) simultaneously into account improved the strength of the correlation with beetle density (Table 5) although the variation explained was not much of an improvement over the combined influence of just maximum temperature and relative humidity (Table 5).

**Table 5:** Linear regression results between monthly beetle density values and climatic variables. *P*-values less than 0.05 are in bold. *n*=47 in all tests.

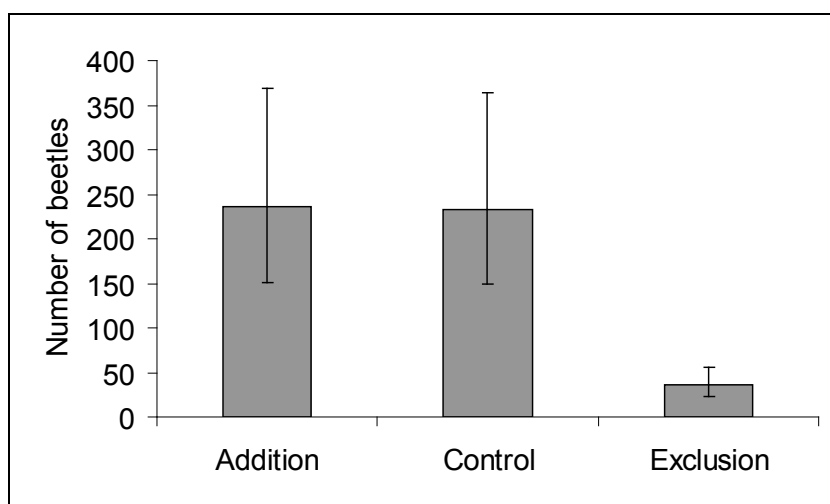
| Climatic variable         | R <sup>2</sup> | <i>P</i> -value   |
|---------------------------|----------------|-------------------|
| Daily average:            |                |                   |
| Mean temperature          | 0.28           | <b>0.0001</b>     |
| Maximum temperature       | 0.29           | <b>&lt;0.0001</b> |
| Minimum temperature       | 0.22           | <b>0.0008</b>     |
| Solar radiation           | 0.04           | 0.17              |
| Relative humidity         | 0.29           | <b>&lt;0.0001</b> |
| Evaporation               | 0.00           | 0.69              |
| Total monthly rainfall    | 0.05           | 0.12              |
| All (multiple regression) | 0.44           | <b>0.0001</b>     |
| Max Temp + RH             | 0.42           | <b>&lt;0.0001</b> |



**Figure 32:** Relationship between two climatic variables and density of leaf litter beetles. (Left) Maximum daily mean temperature. (Right) Mean daily relative humidity.

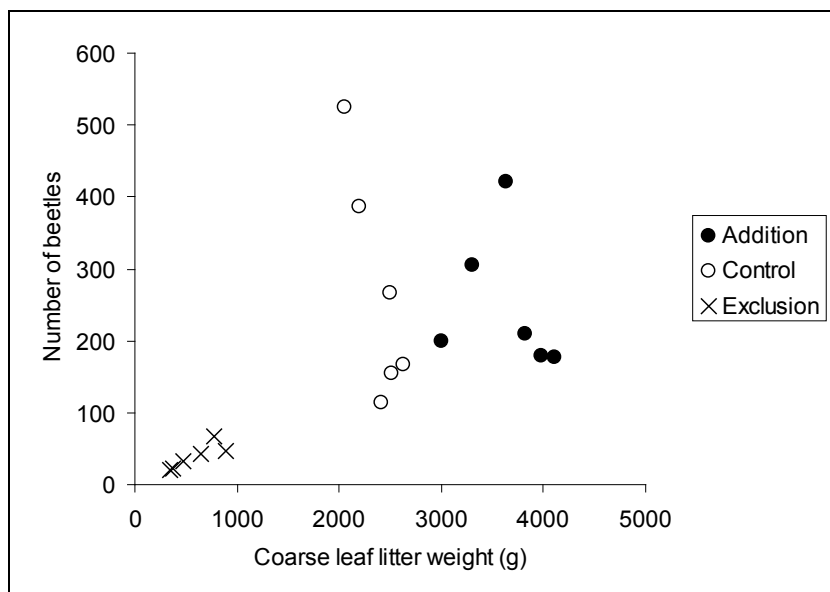
However, simple linear regression fails to take into consideration several important characteristics of time-series data. First, data observations for each variable are not entirely independent of each other. That is observations in one month are likely to be similar to neighbouring observations than would be expected by chance (termed temporal autocorrelation). These potential problems affect both beetle and climatic data. Second, time

lags may operate in the responses of dependant variables. Third, there is co-linearity among predictor variables. Consequently some more robust analyses that account for these problems were conducted using the *Time Series Modeler* routine in the statistical package SPSS. A model was constructed with all the climatic variables as potential explanatory variables (except mean temperature and minimum temperature). This model explained 58.1% of the variation, however, none of the independent variables were identified as significant predictors. From this analysis we can conclude that any simple relationship between temporal variation in beetle density and any climatic variable is likely to be spurious. Climate is still likely to influence temporal variation in beetles but in a complex way, possibly interacting with other factors that display temporal variation such as leaf litter fall.



**Figure 33:** Results of beetle abundance among leaf litter manipulation treatments near the Canopy Crane Research Facility, Cape Tribulation. In this experiment leaf litter was added, excluded (with bird netting) or unaltered (control) to six replicate 3X3m plots over five months.

The leaf litter manipulation experiment, run between September 2008 and February 2009, captured a total of 3337 beetles. The plots where leaf litter was excluded (average of 75% of leaf litter weight excluded) had significantly fewer beetles than control plots or plots where leaf litter was added ( $P=0.05$ , Figure 33). However, there were not significantly more beetles in the leaf litter addition plots than the control plots (Figure 33). These results show that leaf litter fall influences beetle population fluctuations although beetle responses to variations in leaf litter fall appear to show threshold responses. That is beetle abundance increases with leaf litter fall up to a point but above this level, additional leaf litter has little influence on beetles. Further analyses showed that beetle abundance was significantly correlated with coarse leaf litter dry weight ( $n=18$ ,  $p=0.015$ ,  $r^2=0.32$ ; Figure 34) but not fine leaf litter dry weight ( $n=18$ ,  $p=0.27$ ,  $r^2=0.02$ ). This result is initially puzzling because it suggests that the leaf litter addition treatment (which consisted of coarse leaf litter only) should have shown an increase in beetle abundance. However, overall this result confirms our interpretation that the beetles show a threshold response to leaf litter volume.



**Figure 34:** Results of beetle abundance and coarse leaf litter weight among leaf litter manipulation treatments near the Canopy Crane Research Facility, Cape Tribulation.

## Summary

It is extremely difficult to disentangle the influence of temporal variation in climate from temporal variation in resource quality/ quantity. Climate *is* likely to influence temporal variation in insects but in a complex way. Likewise temporal variation in resource quality and quantity is also important, but to a point as insect responses are non-linear. In all likelihood, the consequences of climate change to leaf litter insects depend on alterations to litter fall dynamics among plants as well as plant productivity. The complexity in climatic relationships suggest a degree of resilience among insects to cope with climatic variability.

## References

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- Baldocchi**, D.D. (2003) Assessing ecosystem carbon balance: Problems and prospects of the eddy covariance technique. *Global Change Biology* 9: 479-492
- Boulter**, S.L., Kitching, R.L. and Howlett, B.G. (2006) Family, visitors and the weather: Patterns of flowering in tropical rain forests of northern Australia. *Journal of Ecology* 94: 369-382.
- Brearley**, F.Q., Proctor, J., Suriantata, Nagy, L., Dalrymple, G. and Voysey, B.C. (2007) Reproductive phenology over a ten year period in a lowland evergreen rain forest of central Borneo. *Journal of Ecology* 95: 828-839.
- Capers**, R.S. and Chazdon, R.L. (2004) Rapid assessment of understory light availability in a wet tropical forest. *Agricultural and Forest Meteorology* 123: 177-185.
- Chave**, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromand, F., Higuchi, N., Kira, T., Lescure J.-P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B. and Yamakura, T. (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87-99.
- Crutzen**, P.J., Fall, R., Galbally, I. and Lindinger, W. (1999) Parameters for global ecosystem models. *Nature* 399: 535.
- Doorenbos**, J. and Pruitt, W.O. (1977) Guidelines for Predicting Crop Water Requirements, FAO Irrigation and Drainage Paper No.24, Rome.
- Greenberg**, J.P., Guenther, A. B., Pétron, G., Wiedinmyer, C., Vega, O., Gatti, L.V., Tota, J. and Fisch, G. (2004) Biogenic VOC emissions from forested Amazonian landscapes. *Global Change Biology* 10: 651-662.
- Grimbacher** P.S. and Stork N.E. (2009) Seasonality of a Diverse Beetle Assemblage Inhabiting Lowland Tropical Rainforest in Australia. *Biotropica* 41: 328-37.
- Hamilton**, A. J., Basset, Y., Benke, K.K., Grimbacher, P.S., Miller, S.E., Novotny, V., Samuelson, A., Stork, N.E., Weiblen G.D. and Yen J.D.L. (2010) Reducing uncertainty in estimating global arthropod species richness. *American Naturalist*.
- Hattenschwiler**, S., Tiunov, A.V. and Scheu, S. (2005) Biodiversity and litter decomposition interrestrial ecosystems. *Annual Review of Ecology, Evolution and Systematics* 36: 191-218.
- Hilbert**, D.W. (2008) The dynamic forest landscape of the Australian Wet Tropics: Present, past and future. In: Stork, N. and Turton, S. (eds.) *Living in a Dynamic Tropical Forest Landscape*, Blackwell, Oxford.
- Hopkins**, M.S., Head, J., Ash, J., Hewett, R.K. and Graham, A.W. (1996) Evidence of Holocene and continuing recent expansion of lowland rain forest in humid, tropical North Queensland. *Journal of Biogeography* 23: 737-745.
- Hutyra**, L.R., Munger, J.W., Saleska, S.R., Gottlieb, E., Daube, B.C., Dunn, A.L., Amaral, D.F., de Camargo, P.B. and Wofsy, S.C. (2007) Seasonal controls on the exchange of carbon and water in an Amazonian rain forest. *Journal of Geophysical Research*. 112 [doi:10.1029/2006JG000365].

**Illic**, J., Boland, D., McDonald, M., Downes, G. and Blakemore, P. (2003) Updated Australian Species Wood Density Database – July 2003 Woody Density Phase 1 – State of Knowledge National Carbon Accounting System – Technical Report No. 18.

**Isbell**, R.F. (1996) *The Australian Soil Classification*. CSIRO Publishing: Collingwood.

**Johnson**, S.D. (1992) Climate and phylogenetic determinants of flowering seasonality in the Cape flora. *Journal of Ecology* 81: 567-572.

**Kaspari**, M. and Yanoviak, S.P. (2009) Biogeochemistry and the structure of tropical brown food webs. *Ecology* 90: 3342-3351.

**Kitching**, R. L. (2006) Crafting the pieces of the diversity jigsaw puzzle. *Science* 313: 1055-1057.

**Knicker**, H. (2007) How does fire affect the nature and stability of soil organic nitrogen and carbon? A review. *Biogeochemistry* 85: 91-118.

**Lewis**, S.L., Lloyd, J., Sitch, S., Mitchard, E.T.A. and Laurance, W.F. (2009) Changing ecology of tropical forests: Evidence and drivers. *Annual Review of Ecology, Evolution, and Systematics* 40: 529-549.

**Liddell**, M.J., Nieullet, N., Campoe, O.C. and Freiberg, M. (2007) Assessing the above-ground biomass of a complex tropical rainforest using a canopy crane. *Austral Ecology* 32: 43-58.

**McJannet**, D., Fitch, P., Disher, M. and Wallace, J. (2007) Measurements of transpiration in four tropical rainforest types of north Queensland, Australia. *Hydrological Processes* [doi: 10.1002/hyp.6576]

**Miller-Rushing**, A.J., and Inouye, D.W. (2009) Variation in the impact of climate change on flowering phenology and abundance: An examination of two pairs of closely related wildflowers species. *American Journal of Botany* 96(10):1821-1829.

**Molau**, U., Nordenhall, U. and Eriksen, B. (2005) Onset of flowering and climate variability in an alpine landscape: A 10 year study from Swedish Lapland. *American Journal of Botany* 92: 422-431.

**Mosquin**, T. (1971) Competition for pollinators as a stimulus for the evolution of flowering times. *Oikos* 22: 398-402.

**Murtha**, G.G., Cannon, M.G. and Smith, C.D. (1996) *Soils of the Babinda-Cairns area, North Queensland*. CSIRO Division of Soils, Divisional Report No. 123.

**Murtha**, G.G. (1989) *Soils of the Mossman Cape Tribulation area, North Queensland*. CSIRO Division of Soils, Divisional Report No. 102.

**Nelson**, P.N. and Baldock, J.A. (2005) Estimating the molecular composition of a diverse range of natural organic materials from solid-state <sup>13</sup>C NMR and elemental analyses. *Biogeochemistry* 72: 1-34.

**Stork**, N.E, Balston, J., Farquhar, G.D., Franks, P.J., Holtum, J.A.M. and Liddell, M.J. (2007) Tropical rainforest canopies and climate change. *Austral Ecology* 32: 105-112.

**Ohashi**, M., Kumagai T., Kume, T., Gyokusen, K., Saitoh, T.M. and Suzuki, M. (2008) Characteristics of soil CO<sub>2</sub> efflux variability in an aseasonal tropical rainforest in Borneo Island. *Biogeochemistry* 90: 275-289.

**Rayment**, G.E. and Higginson, F.R. (1992) *Australian laboratory handbook of soil and water chemical methods*. Inkata Press, Melbourne.

**Tracey**, J.G. and Webb, L.J. (1975) *Key to the vegetation of the humid tropical region of North Queensland, with 15 maps at 1:100,000 scale*. CSIRO Long Pocket Laboratories, Indooroopilly, Queensland.

**Waser**, N.M. (1979) Pollinator availability as a determinant of flowering time in Ocotillo (*Fouquieria splendens*). *Oecologia* 39: 107-121.

**Wright**, S.J. (1996) Phenological responses to seasonality in tropical forest plants. *Tropical Forest Plant Ecophysiology* (eds. S. S. Mulkey, R.L. Chazdon and A.P. Smith), pp. 440-460. Chapman & Hall, New York.

**Zuur**, A.E., Ieno, E.N., Walker, N.J., Saveliev, A.A. and Smith, G.M. (2009) *Mixed Effects Models and Extensions in Ecology with R*. Springer, NY.

## Appendix 1

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### Objective (b) – Plant Physiology

Results of post-hoc 95% simultaneous confidence intervals for specified Pairwise comparisons for AGB mean monthly increment between time periods combinations, by the Tukey method. No pairwise comparisons significantly different (see legend Figure 14 for details).

Critical point: 2.7338

Response variable: Intimstandard

Intervals excluding 0 are flagged by '\*\*\*\*\*'

| Estimate    | Std. Error | Lower Bound | Upper Bound |
|-------------|------------|-------------|-------------|
| 1-2 0.0393  | 0.135      | 0.331       | 0.409       |
| 1-3 0.0566  | 0.137      | -0.317      | 0.430       |
| 1-4 0.0722  | 0.135      | -0.298      | 0.442       |
| 1-5 -0.0420 | 0.135      | -0.411      | 0.327       |
| 2-3 0.0172  | 0.137      | -0.358      | 0.392       |
| 2-4 0.0328  | 0.136      | -0.338      | 0.404       |
| 2-5 -0.0813 | 0.135      | -0.451      | 0.289       |
| 3-4 0.0156  | 0.137      | -0.359      | 0.391       |
| 3-5 -0.0985 | 0.137      | -0.472      | 0.275       |
| 4-5 -0.1140 | 0.135      | -0.484      | 0.256       |

## Appendix 2

### Objective (b) – Plant Physiology

Results of post-hoc 95 % simultaneous confidence intervals for specified Pairwise comparisons for AGB mean monthly increment between families, by the Tukey method.

Critical point: 3.2143

Response variable: Inchange

Intervals excluding 0 are flagged by '\*\*\*\*'

|                               | Estimate | Std. Error | Lower Bound | Upper Bound  |
|-------------------------------|----------|------------|-------------|--------------|
| Apocynaceae-Euphorbiaceae     | -1.51000 | 0.754      | -3.930      | 0.9180       |
| Apocynaceae-Fabaceae          | -2.93000 | 0.704      | -5.190      | -0.6650****  |
| Apocynaceae-Lauraceae         | -1.66000 | 0.474      | -3.180      | -0.1360****  |
| Apocynaceae-Meliaceae         | -2.21000 | 0.497      | -3.810      | -0.6090 **** |
| Apocynaceae-Myristicaceae     | -0.94000 | 0.479      | -2.480      | 0.6010       |
| Apocynaceae-Myrtaceae         | -2.16000 | 0.448      | -3.         | -0.7210 **** |
| Apocynaceae-Proteaceae        | -2.30000 | 0.522      | -3.980      | -0.6270 **** |
| Apocynaceae-Sapindaceae       | -2.17000 | 0.704      | -4.430      | 0.0955       |
| Apocynaceae-Sterculiaceae     | -2.04000 | 0.543      | -3.780      | -0.2900 **** |
| Euphorbiaceae-Fabaceae        | -1.42000 | 0.904      | -4.320      | 1.4900       |
| Euphorbiaceae-Lauraceae       | -0.15300 | 0.739      | -2.530      | 2.2200       |
| Euphorbiaceae-Meliaceae       | -0.70100 | 0.754      | -3.130      | 1.7200       |
| Euphorbiaceae-Myristicaceae   | 0.56800  | 0.743      | -1.820      | 2.9500       |
| Euphorbiaceae-Myrtaceae       | -0.65300 | 0.723      | -2.980      | 1.6700       |
| Euphorbiaceae-Proteaceae      | -0.79600 | 0.771      | -3.270      | 1.6800       |
| Euphorbiaceae-Sapindaceae     | -0.65800 | 0.904      | -3.560      | 2.2500       |
| Euphorbiaceae-Sterculiaceae - | 0.52800  | 0.785      | -3.050      | 2.0000       |
| Fabaceae-Lauraceae            | 1.27000  | 0.687      | -0.943      | 3.4800       |
| Fabaceae-Meliaceae            | 0.71900  | 0.704      | -1.540      | 2.9800       |
| Fabaceae-Myristicaceae        | 1.99000  | 0.691      | -0.234      | 4.2100       |
| Fabaceae-Myrtaceae            | 0.76600  | 0.669      | -1.390      | .9200        |
| Fabaceae-Proteaceae           | 0.62300  | 0.721      | -1.690      | 2.9400       |
| Fabaceae-Sapindaceae          | 0.76100  | 0.862      | -2.010      | 3.5300       |
| Fabaceae-Sterculiaceae        | 0.89100  | 0.737      | -1.480      | 3.2600       |
| Lauraceae-Meliaceae           | -0.54800 | 0.474      | -2.070      | 0.9770       |
| Lauraceae-Myristicaceae       | 0.72100  | 0.455      | -0.743      | 2.1800       |
| Lauraceae-Myrtaceae           | -0.50000 | 0.422      | -1.860      | 0.8560       |
| Lauraceae-Proteaceae          | -0.64400 | 0.500      | -2.250      | 0.9630       |
| Lauraceae-Sapindaceae         | -0.50600 | 0.687      | -2.720      | 1.7000       |
| Lauraceae-Sterculiaceae       | -0.37600 | 0.522      | -2.050      | 1.3000       |
| Meliaceae-Myristicaceae       | 1.27000  | 0.479      | -0.273      | 2.8100       |
| Meliaceae-Myrtaceae           | 0.04780  | 0.448      | -1.390      | 1.4900       |
| Meliaceae-Proteaceae          | -0.09580 | 0.522      | -1.770      | 1.5800       |
| Meliaceae-Sapindaceae         | 0.04210  | 0.704      | -2.220      | 2.3000       |
| Meliaceae-Sterculiaceae       | 0.17200  | 0.543      | -1.570      | 1.9200       |
| Myristicaceae-Myrtaceae       | -1.22000 | 0.428      | -2.600      | 0.1540       |
| Myristicaceae-Proteaceae      | -1.36000 | 0.505      | -2.990      | 0.2580       |

|                             | Estimate | Std. Error | Lower Bound | Upper Bound |
|-----------------------------|----------|------------|-------------|-------------|
| Myristicaceae-Sapindaceae   | -1.23000 | 0.691      | -3.450      | 0.9940      |
| Myristicaceae-Sterculiaceae | -1.10000 | 0.527      | -2.790      | 0.5970      |
| Myrtaceae-Proteaceae        | -0.14400 | 0.475      | -1.670      | 1.3800      |
| Myrtaceae-Sapindaceae       | -0.00572 | 0.669      | -2.160      | 2.1500      |
| Myrtaceae-Sterculiaceae     | 0.12400  | 0.498      | -1.480      | 1.7300      |
| Proteaceae-Sapindaceae      | 0.13800  | 0.721      | -2.180      | 2.4600      |
| Proteaceae-Sterculiaceae    | 0.26800  | 0.566      | -1.550      | 2.0900      |
| Sapindaceae-Sterculiaceae   | 0.13000  | 0.737      | -2.240      | 2.5000      |

Species list and sample size for trees (>10 cm DBH) included in dendrometer study at Canopy Crane Research Facility, Cape Tribulation, North Queensland, Australia.

| Family         | Genus                 | Species                                         | n  |
|----------------|-----------------------|-------------------------------------------------|----|
| Anacardiaceae  | <i>Semecarpus</i>     | <i>Semecarpus australiensis</i>                 | 2  |
| Apocynaceae    | <i>Alstonia</i>       | <i>Alstonia scholaris</i>                       | 14 |
| Apocynaceae    | <i>Wrightia</i>       | <i>Wrightia laevis</i> (subsp. <i>millgar</i> ) | 4  |
| Burseraceae    | <i>Canarium</i>       | <i>Canarium vitiense</i>                        | 1  |
| Cunoniaceae    | <i>Gillbeea</i>       | <i>Gillbeea adenopetala</i>                     | 4  |
| Elaeocarpaceae | <i>Elaeocarpus</i>    | <i>Elaeocarpus angustifolius</i>                | 2  |
| Euphorbiaceae  | <i>Cleistanthus</i>   | <i>Cleistanthus myrianthus</i>                  | 4  |
| Euphorbiaceae  | <i>Rockinghamia</i>   | <i>Rockinghamia angustifolia</i>                | 1  |
| Fabaceae       | <i>Castanospermum</i> | <i>Castanospermum australe</i>                  | 6  |
| Lauraceae      | <i>Endiandra</i>      | <i>Endiandra microneura</i>                     | 10 |
| Lauraceae      | <i>Cryptocarya</i>    | <i>Cryptocarya mackinnoniana</i>                | 7  |
| Lauraceae      | <i>Cryptocarya</i>    | <i>Cryptocarya grandis</i>                      | 3  |
| Lauraceae      | <i>Cryptocarya</i>    | <i>Cryptocarya hypospodia</i>                   | 1  |
| Lauraceae      | <i>Cryptocarya</i>    | <i>Cryptocarya murrayi</i>                      | 1  |
| Lauraceae      | <i>Litsea</i>         | <i>Litsea leefeana</i>                          | 1  |
| Meliaceae      | <i>Dysoxylum</i>      | <i>Dysoxylum pettigrewianum</i>                 | 7  |
| Meliaceae      | <i>Dysoxylum</i>      | <i>Dysoxylum papuanum</i>                       | 5  |
| Meliaceae      | <i>Dysoxylum</i>      | <i>Dysoxylum alliaceum</i>                      | 4  |
| Meliaceae      | <i>Dysoxylum</i>      | <i>Dysoxylum arborescens</i>                    | 1  |
| Meliaceae      | <i>Toona</i>          | <i>Toona ciliata</i>                            | 1  |
| Monimiaceae    | <i>Doryphora</i>      | <i>Doryphora aromatica</i>                      | 1  |
| Monimiaceae    | <i>Tetrasynandra</i>  | <i>Tetrasynandra laxiflora</i>                  | 1  |
| Myristicaceae  | <i>Myristica</i>      | <i>Myristica insipida</i>                       | 21 |
| Myrtaceae      | <i>Acmena</i>         | <i>Acmena graveolens</i>                        | 11 |
| Myrtaceae      | <i>Syzygium</i>       | <i>Syzygium gustavioides</i>                    | 8  |
| Myrtaceae      | <i>Syzygium</i>       | <i>Syzygium sayeri</i>                          | 8  |
| Myrtaceae      | <i>Syzygium</i>       | <i>Syzygium cormiflorum</i>                     | 1  |

| <b>Family</b>    | <b>Genus</b>           | <b>Species</b>                   | <b>n</b> |
|------------------|------------------------|----------------------------------|----------|
| Myrtaceae        | <i>Syzygium</i>        | <i>Syzygium kuranda</i>          | 1        |
| Proteaceae       | <i>Cardwellia</i>      | <i>Cardwellia sublimis</i>       | 11       |
| Proteaceae       | <i>Musgravea</i>       | <i>Musgravea heterophylla</i>    | 3        |
| Proteaceae       | <i>Austromuelleria</i> | <i>Austromuelleria trinervia</i> | 1        |
| Rhamnaceae       | <i>Emmanosperma</i>    | <i>Emmanosperma cunninghamii</i> | 1        |
| Rubiaceae        | <i>Antirhea</i>        | <i>Antirhea tenuiflora</i>       | 1        |
| Rubiaceae        | <i>Neonauclea</i>      | <i>Neonauclea glabra</i>         | 1        |
| Sapindaceae      | <i>Synima</i>          | <i>Synima cordierorum</i>        | 5        |
| Sapindaceae      | <i>Ganophyllum</i>     | <i>Ganophyllum falcatum</i>      | 1        |
| Sapotaceae       | <i>Palaquium</i>       | <i>Palaquium galactoxylon</i>    | 1        |
| Sterculiaceae    | <i>Argyrodendron</i>   | <i>Argyrodendron peralatum</i>   | 13       |
| Xanthophyllaceae | <i>Xanthophyllum</i>   | <i>Xanthophyllum octandrum</i>   | 1        |