Journal of Tropical Ecology (2004) **20**:583–586. Copyright © 2004 Cambridge University Press
DOI: 10.1017/S0266467404001622 Printed in the United Kingdom

SHORT COMMUNICATION

Immediate impacts of a severe tropical cyclone on the microclimate of a rain-forest canopy in north-east Australia

Stephen M. Turton[1] and Danny T. Siegenthaler

Rainforest Cooperative Research Centre, School of Tropical Environment Studies and Geography, James Cook University, P.O. Box 6811, Cairns, Queensland 4870, Australia
(*Accepted 30th October 2003*)

Key Words: canopy disturbance, photosynthetically active radiation, rain forest, temperature, vapour pressure deficit

Tropical cyclones, which are frequent along the north-eastern Australian coast, can result in severe disturbances to rain forests in the region (Grove *et al*. 2000, Webb 1958). Branch breakages and tree falls result in high levels of light penetration to the forest floor, which is normally heavily shaded (Turton 1992). This change in microclimate stimulates the growth of normally suppressed seedlings, the germination of seeds that are triggered by sunlight (Chazdon 1988), and often, invasion by weeds. Fragmented rain forests, that are common in the region, are particularly vulnerable to impacts of cyclones because of their large edge to forest area ratio. Appropriate management of such rain forests, following catastrophic disturbance, requires a thorough understanding of recovery processes at a number of temporal and spatial scales (Grove *et al*. 2000).

Severe Tropical Cyclone 'Rona', with maximum wind gusts over 180 km h^{-1}, crossed the north-east Australian coast near Cape Tribulation on 11 February 1999. Broad-scale effects of the cyclone on the rain forests of the area have been described in Grove *et al*. (2000). In this paper we examine the immediate impacts of the cyclone on the microclimate of the rain-forest canopy at the Australian Canopy Crane Research Facility near Cape Tribulation (16°17′S, 145°27′E, 80 m asl), which experienced the direct impact of the storm's core. We believe this is the first study to document the profound changes in forest canopy microclimate before and after a major storm. Such studies have been difficult previously because of the problem of gaining access to the canopy and because of the small odds of a research facility, such as the canopy crane site, being in the direct path of a severe storm.

Microclimates of tropical rain forests have long fascinated ecologists (Longman & Jeník 1987, Richards 1952, Whitmore 1990), but most studies have focused on intact canopies with their characteristic regimes for photosythetically active radiation (PAR), temperature, relative humidity and wind (Aoki *et al*. 1975). A large number of researchers have measured aspects of canopy damage and structural change following cyclones, typhoons and hurricanes (see Grove *et al*. 2000). In comparison, few studies have considered microclimate patterns across rain-forest understoreys following canopy disturbance (Bellingham *et al*. 1996, Fernandez & Fetcher 1991, Turton 1992), and none have documented microclimate changes within the main canopy. Given that the canopy is the powerhouse of the rain forest in terms of productivity (Parker 1995) as well as containing significant biodiversity, understanding the magnitude of changes associated with a catastrophic natural disturbance within the canopy will contribute to our understanding of long-term dynamics of such complex ecosystems.

Microclimate measurements commenced at the Australian Canopy Crane site in December 1998, consisting of two types of monitoring (Turton *et al*. 1999): (1) standard meteorological measurements using an automatic weather station (AWS) in a large clearing, adjacent to the crane; (2) profile measurements of air temperature, relative humidity and PAR at three heights on the crane tower. Vapour pressure deficit (VPD) was calculated from the temperature and humidity data according to Oke (1987). In this paper we present PAR, air temperature and VPD measurements taken from the crane tower for 6 d immediately before and after the cyclone to demonstrate the enormous changes caused by the defoliation and structural damage to the canopy.

[1]Corresponding author. Email: Steve.Turton@jcu.edu.au

The canopy crane is located in complex mesophyll vine forest (Tracey 1982) in very wet lowlands. Details of the canopy crane site may be found in Turton *et al.* (1999). The crane is located in a continuous area of primary forest with an average canopy height of 25 m on gently sloping terrain. Plank buttresses, woody lianas, vascular epiphytes and tree palms are prominent. Annual average rainfall is 3800 mm with about 60% falling between December and April. Mean daily temperature ranges from 28 °C in January to 22 °C in July. Soils at the site are well-weathered red podsols derived from phyllites and schists (Date & Ross 1985).

Forest surrounding the crane site suffered moderate to severe damage as a result of the hurricane-force winds. Observations after the storm found about 10% of the trees in the 1-ha plot covered by the canopy crane were completely toppled, about 30% of the trees lost their crowns but remained standing, and most remaining canopy trees were severely defoliated. Many vines, lianas and epiphytes were removed. Figure 1 compares canopy openness at the site before and after the cyclone. Before the cyclone, the canopy was completely closed right up to the crane tower, as the structure was constructed within an existing tree fall gap using a helicopter to minimize damage to the canopy.

Table 1 compares external weather conditions, obtained at the AWS in the large clearing adjacent to the crane site, for the 6 d before and after the cyclone. The actual day of the cyclone (11 February 1999) is not included. There are no significant differences ($P > 0.05$) in mean hourly values for solar radiation, air temperature, relative humidity, rainfall and wind for the two 6-d periods. It was assumed that PAR, measured on the tower, was closely correlated with total short-wave irradiation, measured at the nearby AWS. We are therefore confident that any changes within the canopy microclimate for the two measurement periods will be due to the impacts of the cyclone itself, rather than due to differences in regional-scale weather conditions.

Figure 2 shows mean hourly PAR, air temperature and VPD (daylight hours only) for 6 d immediately before and

Figure 1. Hemispherical photographs (hemiphots) of one site within the canopy crane plot before and after Cyclone Rona.

Table 1. Comparisons of mean (± 1 SE) air temperature, relative humidity, rainfall, wind speed and solar radiation for 6 d immediately before Cyclone Rona (5–10 February 1999) and 6 d afterwards (12–17 February 1999). Measurements were taken at the Automatic Weather Station (AWS), located in a large clearing adjacent to the canopy crane plot. Long-term mean values for February are included for comparative purposes. Data for the actual day of the cyclone (11 February 1999) are not included.

6-d period	Mean daily air temperature (°C)	Mean daily relative humidity (%)	Mean daily rainfall (mm)	Mean daily windspeed ($km\ h^{-1}$)	Mean daily solar radiation ($MJ\ m^{-2}\ d^{-1}$)
Before	26.4 ± 0.35	87.5 ± 1.54	48.2 ± 40.92	33.3 ± 1.09	16.2 ± 2.83
After	26.9 ± 0.81	85.8 ± 2.30	38.3 ± 14.15	20.9 ± 5.46	14.2 ± 3.13
F value (P value)	0.38 (0.55)	0.45 (0.52)	0.03 (0.87)	3.78 (0.08)	0.39 (0.54)
Long-term mean for February	26.5	78.0	26.8	26.5	15.8

https://doi.org/10.1017/S0266467404001622 Published online by Cambridge University Press

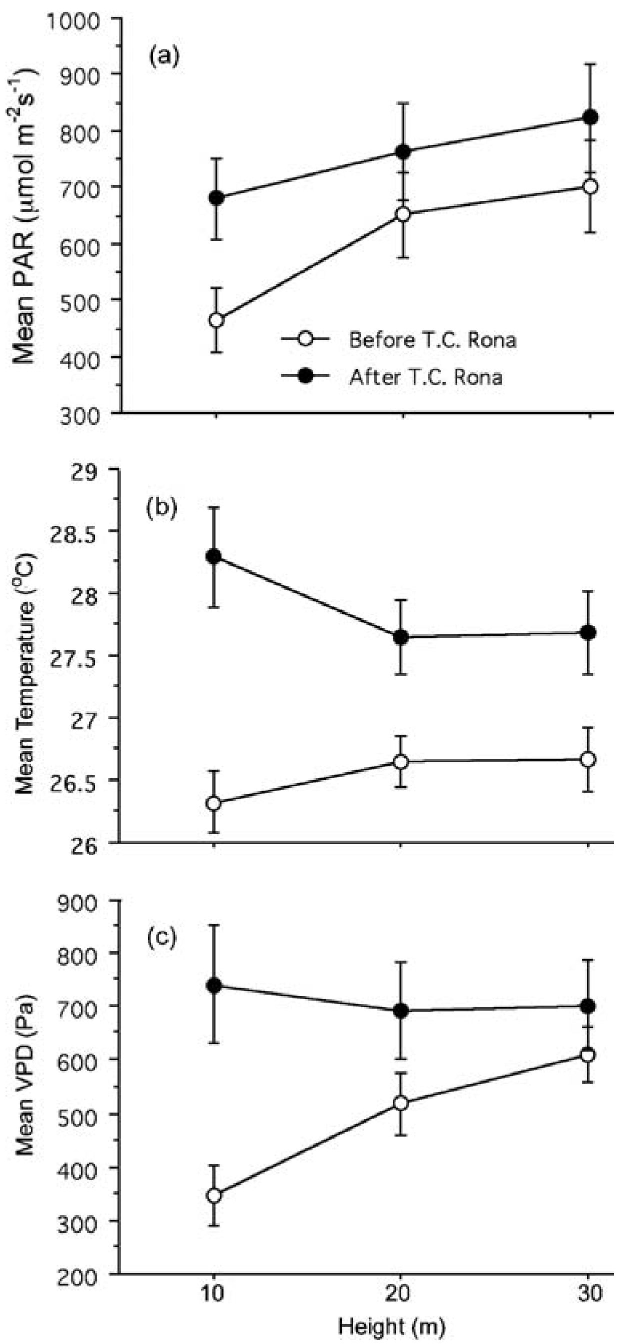

Figure 2: (a) Mean hourly photosynthetically active radiation (PAR), (b) air temperature and (c) vapour pressure deficit (VPD) at three heights on the canopy crane tower 6 d before Cyclone Rona (5–10 February 1999) and 6 d afterwards (12–17 February 1999). Values shown are means (± 1 SE) for daylight hours only. Data for the actual day of the cyclone (11 February 1999) are not included.

after the cyclone. Mean hourly PAR was significantly higher ($F = 5.39$, $P = 0.0226$) after the cyclone at a height of 10 m above the ground, but was not significantly different ($P > 0.05$) at 20 and 30 m above the ground despite an overall increase through the canopy. Most importantly, PAR levels were 42% higher at 10 m above the ground after the cyclone.

Mean hourly air temperature was significantly higher ($F = 20.1$, $P < 0.001$) after the cyclone at 10 m above the ground, but was not significantly different ($P > 0.05$) at 20 and 30 m despite an overall increase through the canopy (Figure 2). It would appear that the zone of maximum heating, normally located at the top of the canopy (Fitzjarrald & Moore 1995) has shifted down to the subcanopy. After the cyclone mean temperature was about 2 °C warmer at 10 m than before.

Mean VPD was significantly higher ($F = 12.37$, $P < 0.001$) after the cyclone at 10 m above the ground, but was not significantly different ($P > 0.05$) at 20 and 30 m, despite an overall increase through the canopy (Figure 2). As with temperature, the zone of maximum evapotranspiration has shifted from top of the canopy to the subcanopy. After the cyclone, VPD was 390 Pa higher at 10 m than before.

The dramatic increase in light intensities (Figure 2) and associated higher temperatures and VPDs are likely to have had a major impact on ecological and physiological processes in the subcanopy and understorey at a number of temporal scales (Chazdon 1988). Increases in PAR and the amounts of red light in the first few weeks after the cyclone favoured germination of pioneer species in the soil seed bank, and the rapid growth of normally suppressed understorey seedlings and saplings. Moderate increases in PAR between 20 and 30 m above the ground have encouraged rapid growth rates of mid-storey trees in the first few months after the cyclone, mainly due to changes in lateral shading among neighbouring canopy trees (Herwitz *et al.* 2000). Over longer time periods (12–36 mo after the cyclone), changes in net radiation, PAR and red : far red ratios are likely to have affected nutrient cycling, plant reproduction and survivorship, plant architecture and growth and leaf turnover (Chazdon 1988).

This study has documented the immediate effects of severe defoliation and stem and branch breakages on the microclimate of a tropical rain forest canopy, and has demonstrated that the most profound changes affected the subcanopy of the forest. Increases in PAR, air temperature and VPD in the lower canopy following the cyclone undoubtedly impacted on plant taxa normally tolerant of dim, cool and relatively humid conditions (Longman & Jeník 1987). While there were undoubtedly short- and medium-term ecological responses to this natural event, one would expect the forest biomass to eventually recover in the absence of any more direct impacts from tropical cyclones (Grove *et al.* 2000). Current studies at the site are documenting the recovery of the forest within the 1-ha plot covered by the crane.

https://doi.org/10.1017/S0266467404001622 Published online by Cambridge University Press

LITERATURE CITED

AOKI, M., YABUKI, K. & KOYAMA, H. 1975. Micrometeorology and assessment of primary production of a tropical rain forest in West Malaysia. *Agricultural Meteorology* 31:115–124.

BELLINGHAM, P. J., TANNER, E. V. J., RICH, P. M. & GOODLAND, T. C. R. 1996. Changes in light below the canopy of a Jamaican montane rain forest after a hurricane. *Journal of Tropical Ecology* 12:699–722.

CHAZDON, R. L. 1988. Sunflecks and their importance to forest understorey plants. *Advances in Ecological Research* 18:2–63.

DATE, R. A. & ROSS, D. J. 1985. Altitudinal transect studies at Cape Tribulation, North Queensland. III. Notes on soils from the general sampling sites. *Queensland Naturalist* 26:53–57.

FERNANDEZ, D. S. & FETCHER, N. 1991. Changes in light availability following Hurricane Hugo in a subtropical montane forest in Puerto Rico. *Biotropica* 23:393–399.

FITZJARRALD, D. R. & MOORE, K. E. 1995. Physical mechanisms of heat and mass exchange between forests and the atmosphere. Pp. 45–72 in Lowman, M. D. & Nadkarni, M. N. (eds). *Forest canopies*. Academic Press, San Diego.

GROVE, S. J., TURTON, S. M. & SIEGENTHALER, D. T. 2000. Mosaics of canopy openness induced by tropical cyclones in lowland rain forests with contrasting management histories in northeastern Australia. *Journal of Tropical Ecology* 15:883–894.

HERWITZ, S. R., SLYE, R. E. & TURTON, S. M. 2000. Long-term survivorship and crown area dynamics of tropical rain forest canopy trees. *Ecology* 81:585–697.

LONGMAN, K. A. & JENÍK, J. 1987. *Tropical forest and its environment.* (Second edition). Longman Scientific & Technical, Harlow. 347 pp.

OKE, T. R. 1987. *Boundary layer climates.* (Second edition). Methuen, New York. 435 pp.

PARKER, G. G. 1995. Structure and microclimate of forest canopies. Pp. 73–106 in Lowman, M. D. & Nadkarni, M. N. (eds). *Forest canopies*. Academic Press, San Diego.

RICHARDS, P. W. 1952. *The tropical rain forest.* Cambridge University Press, Cambridge. 450 pp.

TRACEY, J. G. 1982. *The vegetation of the humid tropical region of North Queensland.* CSIRO Publications, Melbourne. 124 pp.

TURTON, S. M. 1992. Understorey light environments in a north-east Australian rain forest before and after a tropical cyclone. *Journal of Tropical Ecology* 8:241–252.

TURTON, S. M., TAPPER, N. J. & SODDELL, J. 1999. A proposal to measure diurnal and seasonal energetics above and within a lowland tropical rain forest canopy in northeastern Australia. *Selbyana* 20:345–349.

WEBB, L. J. 1958. Cyclones as an ecological factor in tropical lowland rain forest, north Queensland. *Australian Journal of Botany* 6:220–228.

WHITMORE, T. C. 1990. *An introduction to tropical rain forests*. Clarendon Press, Oxford. 226 pp.