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Complex edge effects on soil moisture and microclimate in central Amazonian forest

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ABSTRACT. We investigated the influence of a four-year-old forest edge near Manaus, Brazil, on soil moisture and vertical profiles of air vapour pressure deficit (VPD) within the forest. Soil moisture was measured (with a neutron probe) 0, 5, 10, 20, 40, 60, 80, 100, 150 and 200 m into the forest from the edge, in undisturbed control areas, and in the pasture. Control soil moisture was better explained by rainfall in the previous 2 or 10 days than by longer-term totals. Soil water potentials $\leqslant -1.5$ MPa occurred at some forest locations during the driest period. The variation in soil moisture with distance from the forest edge was complex, with higher values just inside the edge and depleted zones at the edge and 40–80 m inside it. At a given height, VPD (standardized relative to measurements in the open) was not related to distance from the edge, but VPD increased more with height near the edge than in control areas. The complexity of the edge's influence and the contrast with earlier data from the same edge can be explained by the changing vegetation structure near the edge. Regrowth 'seals' the edge with more leaves that transpire and deplete soil moisture, while protecting the understorey just inside the edge from desiccating conditions. A mosaic of gaps of differing ages develops behind the edge, increasing the variation in microclimatic conditions near the ground and consequently in evapotranspiration and soil moisture.

KEY WORDS: edge effects, forest fragment, microclimate, neutron probe, soil moisture, tropical forest, vegetation structure, VPD.

INTRODUCTION

As deforestation in the Amazon region has increased, not only has total forest area been reduced, but much of the remaining forest has been fragmented (Lovejoy & Oren 1981, Skole & Tucker 1993). Many of the differences between remaining forest fragments and continuous forest are due to the creation of an abrupt edge between forest and surrounding cleared areas (Bierregaard *et al.* 1992, Lovejoy *et al.* 1986). Understanding such edge effects is crucial to understanding how forest fragments differ from continuous forest in terms of both biodiversity and ecosystem processes.

Soil moisture is one of the factors that might be expected to be affected by proximity to an exposed forest edge, but few studies so far have addressed this

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possibility directly. Ranney (1977) and Ranney *et al.* (1981) predicted that soil drought may occur near the edges of forest islands due to increased exposure to solar radiation and wind, which would cause increased evapotranspiration. Kapos (1989) found that, just after the end of the dry season, surface soil moisture was depleted at the edges and in the outer 20 m of recently isolated forest reserves near Manaus. There was little evidence that the soils had reached critically low water potentials that might adversely affect plant growth, but it was unclear whether more severe deficits might occur in the middle of the dry season or whether the gradients in soil moisture would persist as the reserves aged.

The understorey microclimate near a forest edge has been shown to be hotter and drier than that of continuous forest (Kapos 1989, Ranney *et al.* 1981, Williams-Linera 1990), but the extent of the edge's influence is unclear. Kapos (1989) found microclimatic changes up to 60 m from the edge in a forest reserve in the Central Amazon. In contrast, Williams-Linera (1990) found no apparent microclimatic alteration beyond 20 m from the edge in a tropical premontane forest in Panama. One possible explanation for the contrast between these two studies is that the edges involved were of different ages. The change in edge effects over time is as yet poorly understood.

The present study was designed to contribute to our understanding of edge effects on microenvironment in tropical forest fragments. We studied two principal aspects of these edge effects, soil moisture and air vapour pressure deficit, in the same reserve studied by Kapos (1989). We asked: (a) Do significant soil moisture deficits occur during the course of a single seasonal cycle? (b) Did the pattern of variation in soil moisture with distance from the forest edge found by Kapos (1989) persist four years after edge creation? (c) How had variation in microclimate in relation to the forest edge changed over the four years between Kapos' (1989) study and the present one? and (d) Does the variation in microclimate related to a forest edge vary with height above the ground?

METHODS

Site

The study was conducted in central Amazonia in a semi-isolated 100 ha reserve (number 2303 of the Biological Dynamics of Forest Fragments Project, also studied by Kapos 1989) located on the Dimona Ranch (03° 08′ S, 60° 02′ W), *c.* 80 km north of Manaus, Brazil. The forest on the north and west sides of the reserve was felled in April 1984 and burned in October 1984 to create pasture, which had been invaded by patches of low second growth by the time this study was done in 1988–1989.

Annual rainfall in the Manaus region is 2000–2500 mm (Anon. 1978, Santos 1968); monthly rainfall totals of <100 mm occur from July to September. The highest average monthly temperature is 27.9°C in September

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and the lowest is 25.8°C in February–April (Salati 1985). The prevailing winds are from the northeast. The soils are mostly oxisols, which are of sandy-clay texture, acidic, well drained and >10 m deep (Chauvel *et al.* 1991). The vegetation is a dense evergreen 'terra firme' forest, about 25–30 m tall, with emergent trees to 35–40 m and many acaulescent palms in the understorey (Lovejoy *et al.* 1984).

Rainfall and soil moisture

Rainfall was measured daily (except for some weekends) *c.* 800 m away from the reserve. Soil moisture was measured in three 20 m × 200 m transects, running from the western (leeward) edge towards the centre of the reserve and randomly located, avoiding small valleys and steep slopes (Figure 1). Three 20 m × 60 m control transects were located in the middle of the reserve, and one 100-m line transect was located in the pasture 100 m from, and parallel to, the reserve edge (Figure 1). PVC neutron probe access tubes were installed to 95 cm depth in parallel lines in the edge transects at −5, 0 (edge line), 5, 10, 20, 40, 60, 80, 100, 150 and 200 m into the forest from the edge, in the control transects at 500, 520, 540 and 560 m from the edge, and along the line transect in the pasture (−100 m). In each forest transect there were three access tubes (7 m apart) at each distance from the edge, and in the pasture nine tubes were randomly located along the line. Thus, there were 144 tubes in total, nine per distance from the forest edge, providing three true replicates per distance.

Soil moisture volume fraction (MVF) was measured at three depths (25, 50 and 75 cm) using a neutron probe (Type IPE 111, Nucleotronics, Ballerup, Denmark) to make 30-second readings. Data were collected approximately fortnightly from April to December 1988 in the forest transects (16 occasions) and from June to December 1988 in the pasture transect (12 occasions). Before each series of readings, five 30-second readings were taken within the probe shield to stabilize the neutron probe and to check for possible drift in its response.

Neutron probe calibration

The neutron probe was calibrated in the field. Ten consecutive 30-second readings were taken at 25 cm depth in each of 14 randomly chosen access tubes in the field study site, and a soil sample for direct measurement of volumetric water content was collected from within 5 cm of each tube at 20–30 cm depth. These soil samples were weighed and dried at 105°C to stable dry weights. Moisture volume fraction (MVF – volume of water per volume of soil) and bulk density were calculated for each sample. Despite the potential variation of soil characteristics in the field (e.g. bulk density ranged from 1.0 to 1.2 g cm^{-3}), there was a good linear calibration relationship between MVF and normalized neutron probe counts (mean counts in the soil (R)/mean counts in water (Rw); R/Rw = 0.71MVF+0.65, $r^2 = 0.72$). We also attempted a laboratory calibration using disturbed soil in a barrel, but found that we were unable to

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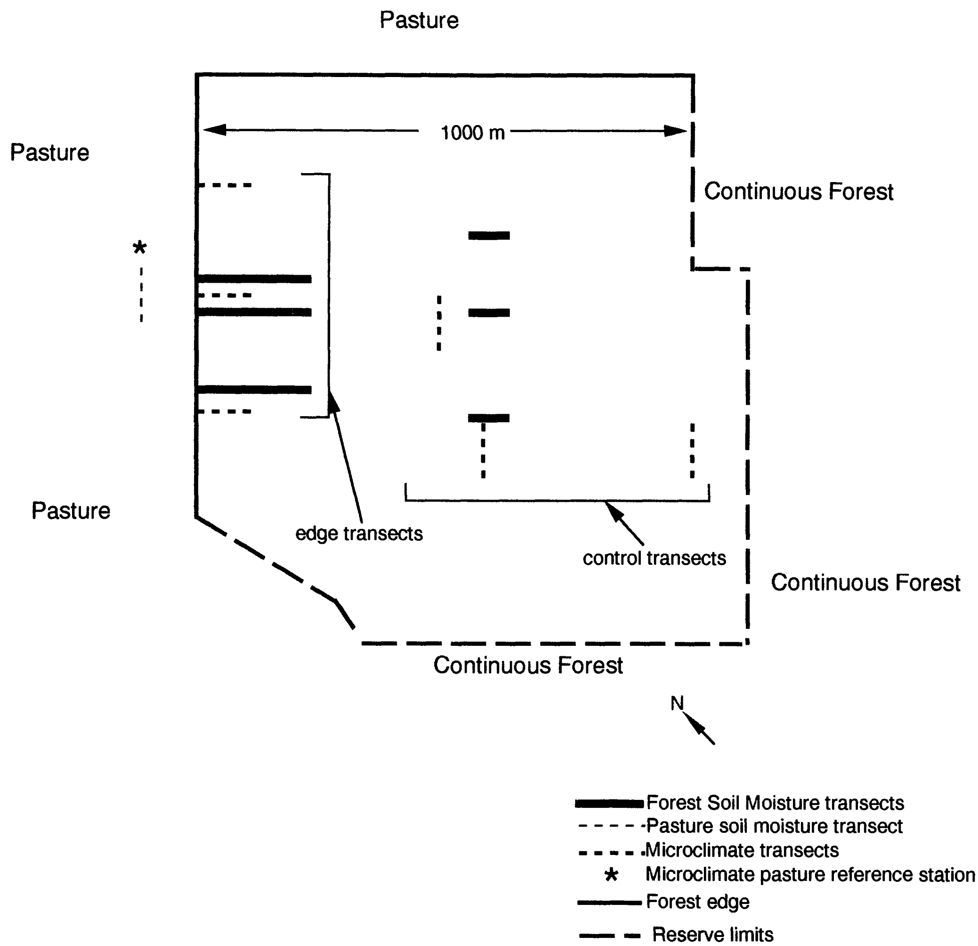

Figure 1. The study area in the semi-isolated 100 ha reserve (no. 2303) on the Dimona ranch, showing the study transects. Three 20 m × 200 m edge transects, three 20 m × 60 m control transects and a 100-m line transect in the pasture were used to study soil moisture. Six 100-m line transects (three edge and three control) and a reference point in the pasture were used for the microclimate study.

approximate field conditions of bulk density or MVF. Therefore, we used the field calibration to convert all the neutron probe readings from the study site to MVF. Although this may have introduced some error due to horizontal and vertical variation in soil characteristics within the site, deriving more field calibrations was not feasible and would have required the destruction of the permanent array of access tubes.

Soil water potential

In each transect, one soil sample (0–25 cm depth) was collected at each distance studied, and these were lumped into two distance intervals (−5 to 80 m and 100 to 200 m) for each edge transect, and into one distance interval (500 to 560 m) for each control transect. These nine composite samples were

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used to determine soil water content at field capacity (−0.03 MPa) and at wilting point (−1.5 MPa) using a pressure plate apparatus (Soil Moisture Equipment Co., Santa Barbara, California).

Soil texture

One soil sample (0–25 cm depth) was collected along each of the tube lines in the edge and control transects. These were lumped into four distance intervals (−5 to 40 m, 60 to 100 m, 150 m and 200 m) for each edge transect, and one distance interval (500 to 560 m) for each control transect. Four samples along the transect line in the pasture were combined in a single composite sample. The 16 compound samples were subjected to standard granulometric analysis, using a combination of sieving and hydrometer methods, and then classified according to texture (USDA 1975).

Slope

Slopes were measured with a clinometer at each intersection point of a 5 m × 5 m grid extending 5 m outside the 20 m wide transects. The access tubes were divided into slope categories of <20%, 21–30% and >30%.

Microclimate

To study the variation of air vapour pressure deficit (VPD) in relation to height above the ground and distance from the reserve edge we used automated ventilated psychrometers (Type WVU, Delta-T Devices, Cambridge, UK) suspended from pulleys along six 100-m line transects; three at the western edge of the reserve perpendicular to the border, and three controls in the centre of the reserve (Figure 1). Six pulleys were installed along each transect, their precise locations depending on the locations of suitable trees. In the edge tansects, the pulleys were at average distances of 12.0 (SE = 2.5), 19.8 (1.0), 39.4 (2.2), 60.3 (3.3), 82.8 (3.1), 97.2 (1.0) m from the edge. The measurement points were dispersed at similar intervals along the control transects, where all were >500 m from the exposed north and west edges of the reserve. At each measurement point, readings were taken at heights of 1.5, 3.0, 5.0, 7.5, 10.0 m above the ground. A station for reference measurements at a height of 1.5 m was located in the pasture 100 m outside the reserve (Figure 1).

Measurements for calculating air VPD were made in March and October–November 1989. Because simultaneous recording at all points was impossible due to the limited amount of equipment available, the following procedure was adopted. On each day of the study, a psychrometer was connected to each of the six pulleys along one study transect. Readings of dry and wet bulb temperatures at the different heights at each point were recorded in a data logger (Delta Logger, Delta-T Devices), which was easily moved between points. Another psychrometer and logger at the reference station in the pasture recorded dry and wet bulb temperatures every 10 min, and VPDs measured in the forest

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were expressed in terms of those measured simultaneously in the pasture. Measurements were made between 10.00 h and 14.00 h on each study day, and the measurement points on the selected transect were monitored in the same order at all heights once per hour.

Vegetation structure

Vegetation structure was estimated using a modification of Hubbell & Foster's (1986) method. A 2.5 m pole was used to make a vertical sighting to estimate foliage density in given height intervals on a scale of 0 (none to very sparse) to 3 (very dense). A range finder was used periodically to confirm height estimates.

For the soil moisture study, vegetation structure in two edge and two control transects was mapped on a 5 m × 5 m grid extending 5 m outside the transects, using height intervals of 0–2, 2–5, 5–10, 10–20, 20–30 and >30 m. The total foliage density over each grid intersection point was expressed as a percentage of the maximum possible score (18), and the foliage density over each neutron probe access tube was averaged from these maps.

For the microclimate study, a square of 25 m^2 centred on each measurement point was divided into a grid of 1 m × 1 m. At every intersection point foliage density was assessed in 0–2, 2–4, 4–6, 6–8, 8–12, 12–20 and >20 m height intervals. The first five of these corresponded to the heights at which VPD measurements were made.

Statistical analysis

The relationships between overall mean soil MVF in the control areas and rainfall totals for 1, 2, 3, 5, 7, 10, 15 and 30 days preceding each reading were examined using stepwise regression. Orthogonal contrast analysis (Genstat 1987) was used to fit the relationship between distance from the edge and MVF. The relationship between mean MVFs for different classes of soil texture, slope and foliage density were examined using Kruskal–Wallis tests.

The standardized VPD data ($VPD_{forest}/VPD_{pasture}$) for each height and distance were arcsin transformed and mean values per distance and per height were calculated using each line transect as one replicate. Microclimate data from edge and control transects were compared by ANOVA, considering distance and height as additional factors.

RESULTS

Rainfall

The rainfall in the study area during 1988 was 2980 mm, *c.* 20% higher than the long-term average for the Manaus region (Salati 1985). Of the 57 rainless days, 40 occurred in August and September, the only two months with <100 mm of rainfall (Figure 2). Peak monthly rainfall (617 mm) was

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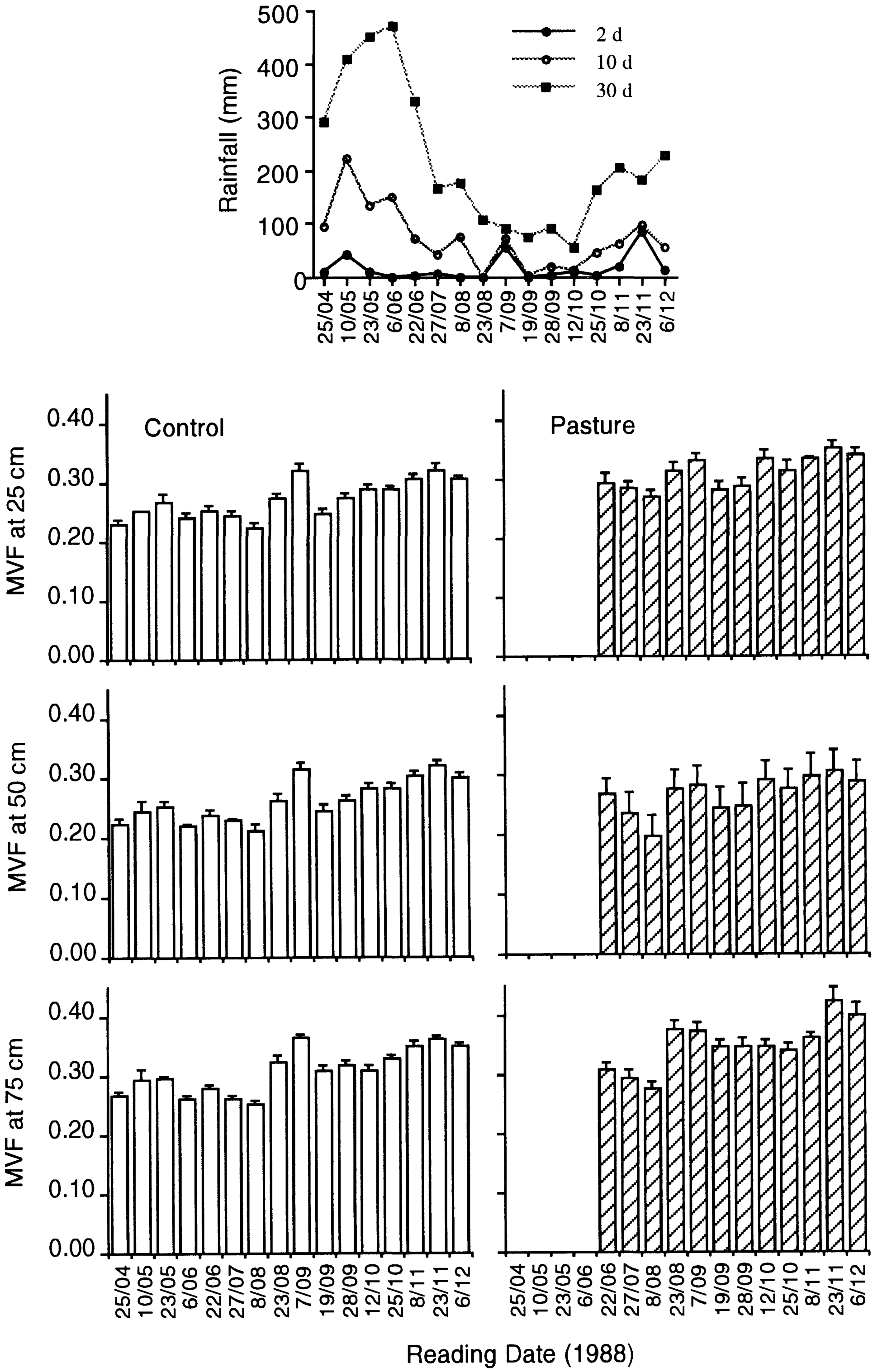

Figure 2. Temporal variation during the 1988 study period of rainfall and mean soil moisture volume fraction (MVF) at three depths in the control areas (N = 3) and in the pasture (N = 9). Rainfall is expressed as totals during the 2, 10 and 30 days preceding each soil moisture measurement. The error bars are ±1 SEM.

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in May, but heavy storms occurred throughout the year, even during the dry season.

Soil moisture

Temporal variation. The temporal variation of mean soil MVF in the control areas was best explained for all depths by the totals of precipitation during the 2 and/or 10 days preceding the soil moisture readings (stepwise regression, $P < 0.05$; Figure 2), rather than by fortnightly or monthly totals of rainfall. The peak MVF observed actually occurred during the 'dry season' (7 September), when a reading was taken two days after a rain storm of 56.5 mm. As expected, MVF was less variable and consistently higher at 75 cm depth than nearer the surface (ANOVA, $P < 0.01$), especially during the dry season. MVF in the pasture had a similar temporal pattern, but was higher than that in the undisturbed forest, with this difference being most pronounced in the dry season (Figure 2).

Throughout the study period the soil water potentials remained above −1.5 MPa in most of the area, but at some locations significant water shortage may have occurred briefly during the driest period (8 August, Figure 3). The available water capacity of the soil was 70 to 85 mm m^{-1}, quite low for tropical soils (Landon 1984), which suggests that extended rainless periods would lead to rapid development of soil water deficits. Waterlogging was never observed in the study area.

Spatial variation. The relation of MVF to distance from the forest edge was more complicated than the simple gradient hypothesized at the outset of the study (Figure 4). Orthogonal contrast analysis showed a significant quartic relationship between MVF and distance from the edge. MVFs in the edge (−5 to 0 m) and 40 to 80 m zones were lower than values recorded in the control areas, while MVFs at 5–20 m and those recorded beyond 100 m from the edge were similar to or higher than those in control areas.

Soil texture

The compound soil samples were classified as clay soils in most of the study site, and as sandy clays in *c.* 20% of the area. The ratio of clay to sand fraction in the samples was used to relate mean MVF at 25 cm depth to soil type by dividing the access tubes into three groups: group I ($N = 38$), those in soils with the highest proportion of clay (>60%) and low proportions of sand (<15%) and silt (<25%); group II ($N = 87$), those in soils with a high proportion of clay (>50%) and about 25% sand and silt; and group III ($N = 18$), those in soils with low proportions of clay and silt and a high proportion of sand (45–60%). Soils belonging to group II had significantly higher mean MVFs than the other two groups (Kruskal–Wallis, $P < 0.001$), which had similar mean MVFs. However, the distribution of these soil types bore little relation to the spatial pattern of soil moisture we recorded (Figure 3).

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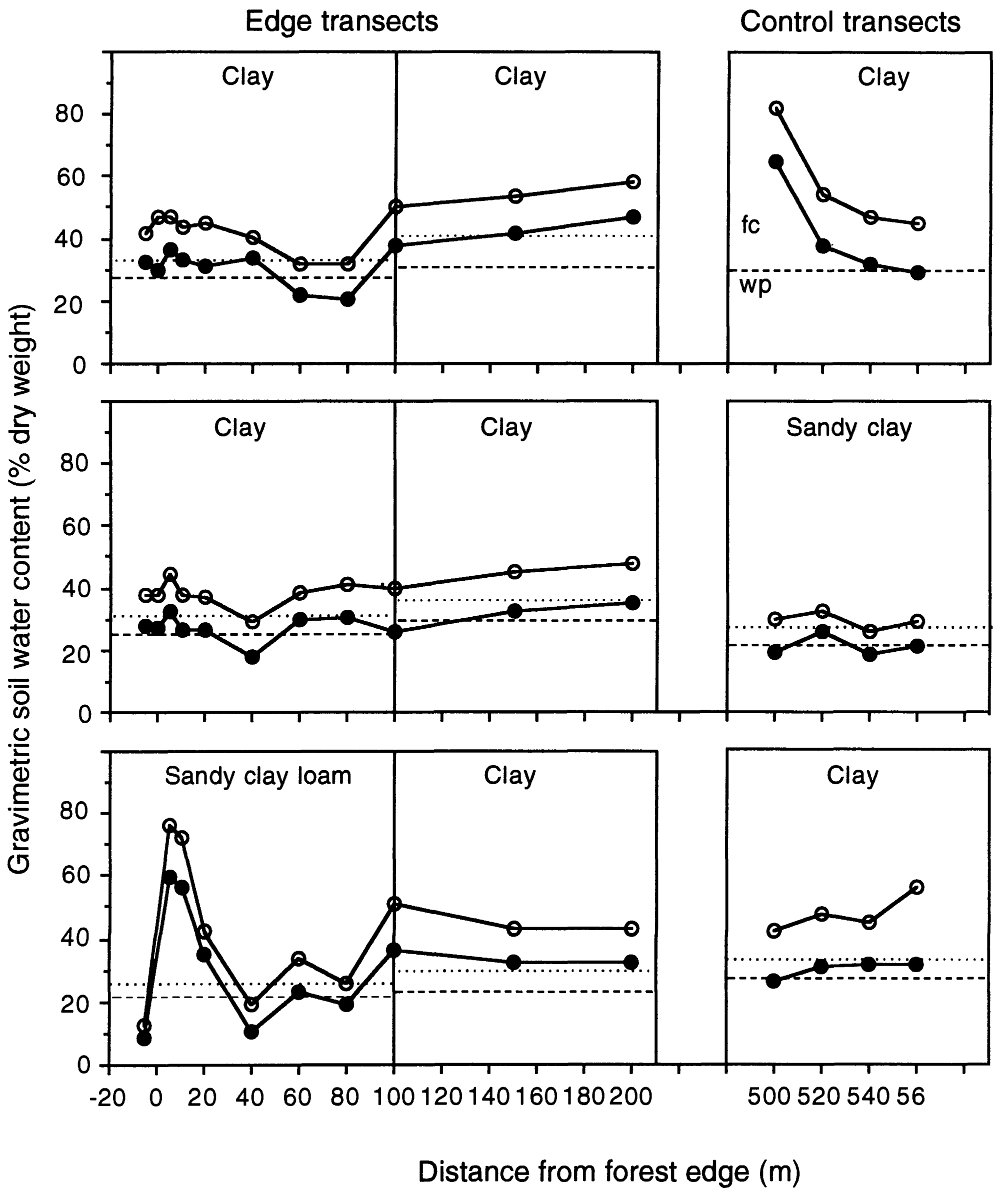

Figure 3. (a) Mean gravimetric soil water content at 25 cm depth in relation to distance from the forest edge, in the driest period (8 August, ●) and in the wettest period (23 November, ○) in the three edge and three control transects. Mean water contents at field capacity (fc · · ·) and at −1.5 MPa (wp – – –) are indicated for sectors from which water retention of composite samples was determined, and soil texture is indicated for the same sectors.

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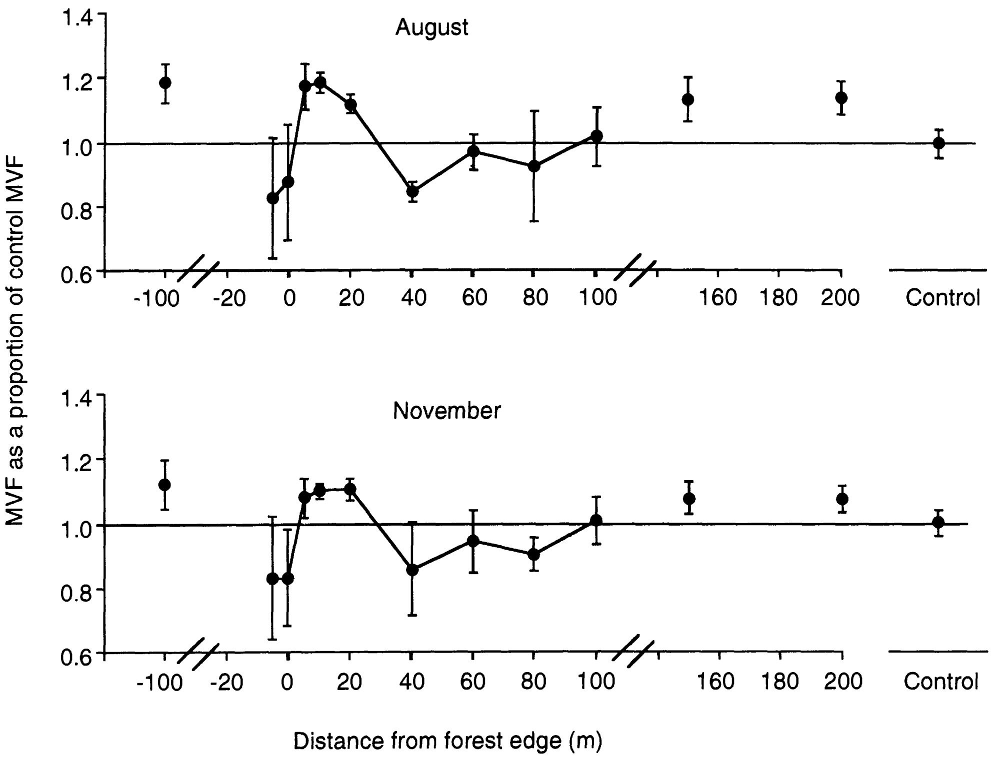

Figure 4. (a) Mean soil moisture volume fraction (MVF) at 25 cm, expressed as a proportion of average MVF in control areas (at 25 cm), in relation to distance from the forest edge for the driest (August) and wettest (November) periods of the study year. Error bars are ±1 SEM (N = 3).

Slope

Slope had no clear effect on MVF at 25 and 50 cm depths, but MVF at 75 cm depth was significantly higher on flat areas than in other slope classes (Kruskal–Wallis, $P < 0.001$). Relatively flat areas predominate in the study site; <30% of the access tubes were on slopes >20%.

Vegetation structure

The height of the greatest foliage density increased steadily with increasing distance from the forest edge up to 80–100 m into the forest (Figure 5). The study area could be divided into four zones of vegetation structure in relation to distance from the forest edge: (1) Where the primary forest was cut, i.e. at the border of the reserve (−5–0 m) and in patches in the pasture, there was a dense shrub layer mostly ≤1.5 m tall. (2) In a zone of older gaps in the outer 20 m of the reserve, where the canopy and sub-canopy had been damaged by storms soon after edge creation, a dense layer of regenerating secondary species gave high foliage density from 5 to 20 m height. (3) A mosaic of primary forest and newer gaps extended from 40 to 80 m from the forest edge; these gaps were predominantly aligned perpendicular to the

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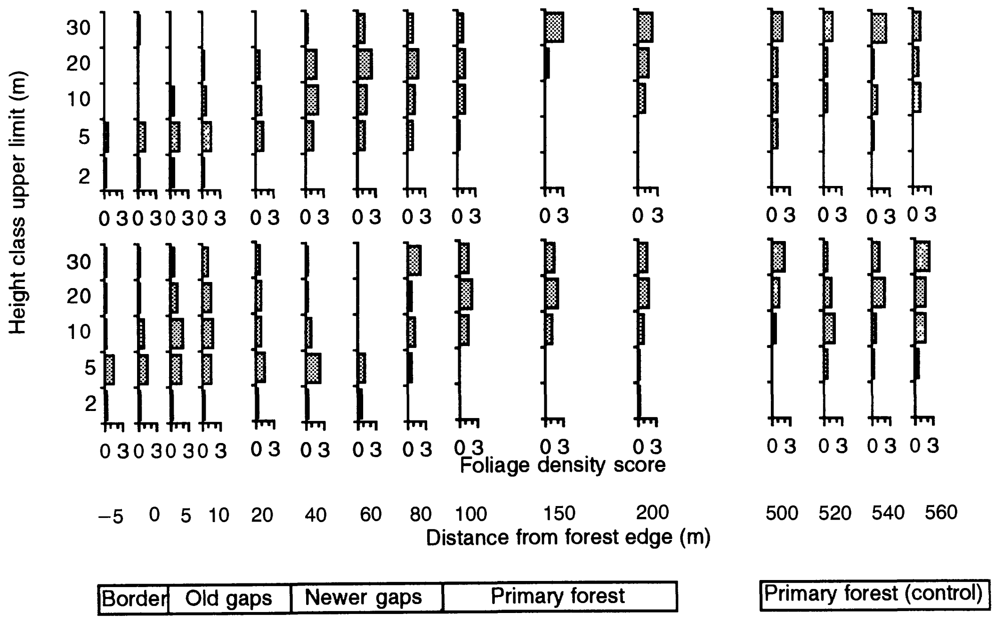

Figure 5. Vertical distribution of foliage density in relation to distance from the forest edge in two edge and two control transects (foliage density was scored from '0 = very sparse' to '3 = very dense' in each height interval). At each distance, the profile of foliage density is the mean of scores over three neutron probe access tubes. The vegetation zones are indicated at the bottom of the figure.

forest edge and had minimum foliage density in most height intervals. (4) The closed canopy of the primary forest zone (>100 m from the edge) gave higher foliage densities above 20 m, and gaps were less frequent and smaller here than in the other zones.

MVF at 25 cm was significantly lower (Kruskal–Wallis, $P < 0.001$) at points with high total foliage density (>50% of maximum possible score) than at points with less dense foliage. High foliage density points were found principally in the remnant tall forest in the new gap zone and in the primary forest zone, but occurred throughout the study area.

Microclimate

In contrast to Kapos' (1989) results, VPD at a given height did not vary significantly with distance along the edge transects (Figure 6), and the difference between the two studies was most marked near the edge.

Mean standardized VPD at a given height did not differ significantly between edge and control transects. VPDs were significantly different between heights (Friedman's test, $P < 0.005$), generally increasing linearly with height above the ground (Figure 7). The slope of the regression between VPD and height was significantly greater (t-test, $P < 0.005$) in the edge than in the control areas during the morning (10.00–12.00), but not during the afternoon. The increase in VPD with height in the edge areas, *c.* 66% from 1.5 to 10 m, was much

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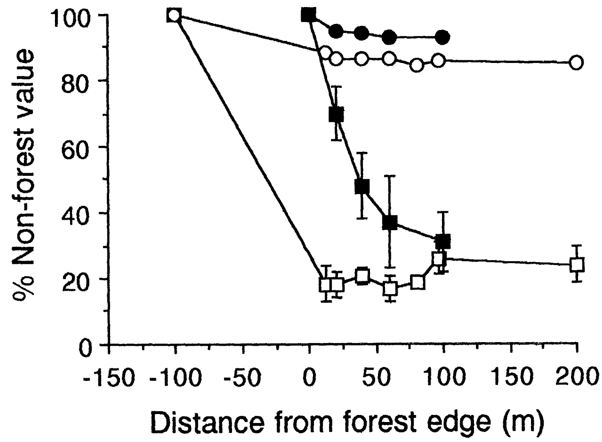

Figure 6. Mean air vapour pressure deficit (VPD, □) and temperature (○), standardized relative to pasture or edge reference points in relation to distance from the forest edge in Dimona reserve 2303 in 1984, 4–6 months after edge creation (open symbols, from Kapos 1989) and in 1989 (closed symbols, this study). Error bars are ±1 SEM.

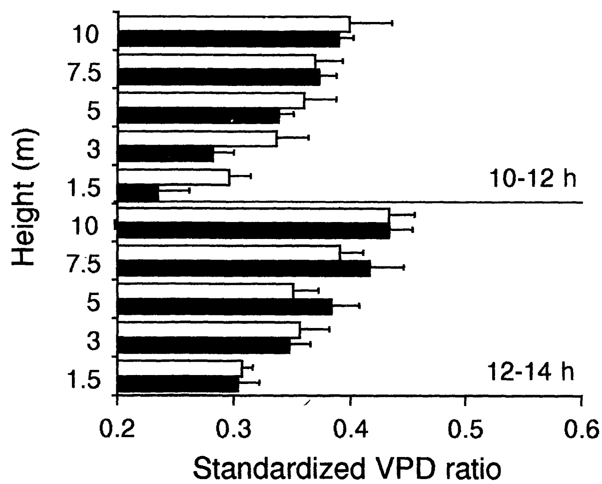

Figure 7. Mean standardized vapour pressure deficit (VPD) ratio ($VPD_{forest}/VPD_{pasture}$) in edge (□) and control transects (■) in relation to height above the ground during two periods of the day. Values are means of three replicates (each comprising six measurement points) and error bars are 1 SEM.

smaller than the 180% increase from 1.5 to 13.5 m found by Roberts *et al.* (1990) in near-by 'terra firme' forest, probably reflecting differences in weather conditions and/or forest structure between the two studies.

Standardized VPD ($VPD_{forest}/VPD_{pasture}$) was significantly negatively correlated with the total of foliage density scores at all heights above the measurement level averaged over a 25 m^2 area around each measurement point ($r^2 = 0.76$).

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DISCUSSION

Soil water availability

The close relationship between soil water content at 25 cm and recent short-term rainfall supports the findings of Leopoldo *et al.* (1982), who reported rapid infiltration and residence times of *c.* one week in this part of the profile at a similar site near Manaus. The good agreement of deeper soil MVFs with recent short-term rainfall patterns is more surprising in the light of the conclusion by Leopoldo *et al.* (1982) that residence times at these depths are in the order of 2–4 weeks, and it suggests that drainage from individual storms, perhaps via the macropore system (Nortcliff & Thornes 1981), may be more rapid than initially supposed.

Although the study year was relatively wet, we found more evidence of soil drought than in Kapos' (1989) study. The driest soils measured during this study had just over half the moisture of those in Kapos' (1989) study (17–33% cf. 35–50% dry wt), and were apparently near wilting point. Thus, it is indeed possible that periodic soil moisture deficits adversely affect plant growth in this system. They may be a cause of the increased tree mortality that has been observed near edges (Bierregaard *et al.* 1992), but, as discussed below, that mortality causes changes in forest structure, which themselves influence the patterns of variation in soil moisture, increasing the difficulty of assessing the role played by local water shortage.

The low available water capacity of the soil was predicted for the soils of this region by Chauvel *et al.* (1991), and similar values were found in water budget studies of near-by sites (Cabral 1991, M. Hodnett *et al.*, unpublished). If evapotranspiration is *c.* 3.5 mm day^{-1} (a conservative estimate, cf. Leopoldo *et al.* 1985, Shuttleworth 1988), and effective rooting depth is *c.* 50 cm (pers. obs. and Cavalier 1989), then available water supplies would be exhausted by as few as 10 consecutive rainless days. Such rainless periods already occur in drier years such as those of El Niño events. They will last longer and occur with increasing frequency in the future if deforestation continues and/or if current global change predictions are accurate (Salati & Vose 1984, Shukla *et al.* 1990, Shuttleworth 1988), so water shortage must be considered a potential limiting factor for this ecosystem.

Edge-related variation

The pattern of variation in both soil moisture and microclimate with increasing distance from the edge differed substantially from the simple gradient to undisturbed forest conditions hypothesized by Ranney (1977) and suggested by Kapos' (1989) results. The patterns we found can most easily be explained in terms of vegetation structure and its change over time, which are themselves affected by proximity to the forest edge (Camargo 1993).

At the creation of a forest edge, the profile along the edge is unaltered but open to penetration by solar radiation and desiccating breezes, resulting in the

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higher understorey VPDs found by Kapos (1989). These influences affect a much greater total leaf area than they do in closed forest, where the canopy protects the lower part of the profile, and they may cause a greater total evapotranspiration resulting in soil moisture depletion near the edge (Kapos 1989). With time, growth by secondary species and branch and leaf production by the original trees 'seal' the profile along the edge. All these additional layers are exposed to direct solar radiation, increasing total evapotranspiration and depleting soil moisture in contrast to undisturbed primary forest, where only the upper leaf layers in the profile are so exposed. This 'sealing' of the edge by denser vegetation, which was found in older edges by Ranney *et al.* (1981) and Williams-Linera (1990), protects the forest just inside it from desiccating conditions. It may explain higher soil moisture and low VPDs just inside the edge and decrease the extent of edge effects near older edges.

At the same time, gaps are formed with greater frequency near the edge than in undisturbed forest and appear to propagate towards the interior of a forest fragment (Camargo 1993, Kapos *et al.* 1993), developing a mosaic of forest and non-forest conditions. This heterogeneity of the vegetation structure behind the edge itself also helps to explain the complexity of spatial variation in microenvironment that we found. In general, gaps are expected to have higher soil moisture and higher VPD than undisturbed forest (Becker *et al.* 1988, Fetcher *et al.* 1985, Vitousek & Denslow 1986), but as gaps age and vegetation regenerates, the effect of reduced leaf area on soil moisture and VPD disappears. In temperate forests this process takes 5–7 years or less (Moore & Vankat 1986), and it may be more rapid in the tropics. Bazzaz (1991) suggested that understorey conditions may return to a tropical treefall gap within two years, and Parker (1985) found that soil moisture in a clearing was similar to that in primary forest after a similar interval.

Thus, the gaps in the 'new gaps' zone may have more than replaced their original leaf area, and this additional leaf area or differences in its distribution may affect rainfall interception. Parker (1985) found that interception by the canopy of 5–7-year-old second growth in Costa Rica was nearly double that in primary forest. Such increased interception by the dense vegetation of the newer gaps zone could help to explain the reduced soil moisture we found there. The secondary vegetation may also be composed of species that characteristically use more water than primary species (L. A. Bruijnzeel, pers. comm.). Furthermore, the gaps in this mosaic probably permit oblique penetration of sunlight to lower layers of the profile of adjacent undisturbed areas, increasing evapotranspiration from those layers.

The patterns of variation in soil moisture and vegetation structure that we found are reminiscent of the wave mortality and regeneration patterns in spruce forest described by Sprugel (1976). It is possible that the creation of a forest edge is similar to the mortality events that he described in that it exposes trees behind the edge to more desiccating conditions, increasing mortality which is then followed by regeneration. The mortality near the edge in turn exposes

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canopy trees farther into the forest to deeper penetration of levels of solar radiation and winds that can be both desiccating and physically damaging. Edges facing the prevailing wind might well show more severe edge effects than those observed on this leeward-facing edge, and their exact extent will depend on the amount of local mortality and consequent disturbance (cf. Palik & Murphy 1990).

However, regeneration in the terra firme forest is much more rapid than in the spruce forests described by Sprugel, and it includes changes in species composition that were not part of the wave regeneration patterns he described (Sprugel 1976). Casual observation suggests that in the Amazonian forest, these changes and the dense belt of regeneration near the forest edge reduce the influence of the edge and hence the instability of the system, limiting the extent of propagation of wave pattern mortality and/or environmental variation.

The two parts of this study both confirm that forest edges are functionally different from continuous forest in terms of microenvironment and (probably) hydrological processes. However, the differences are not the straightforward edge-related gradients initially hypothesized (and found near newly cut forest edges), and they change significantly over time. The clearest effect of the older forest edge is increased environmental heterogeneity, related to changes in forest structure, extending about 100 m into the forest. Species able to tolerate or benefit from such heterogeneity are likely to predominate in edge-affected zones, while others will survive only farther into the forest. However, the changing nature of the forest near the edge means that both the nature and the extent of edge influence will be continuously changing. Any attempt to assess the amount of edge-affected forest in a forest fragment or landscape should incorporate information about the time since edge formation and, if possible, the relative exposure of the edges to gap formation and other disturbance.

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Widianarko, B., Vink, K., & van Straalen, N. M. (eds.) 1994. *Environmental Toxicology in South East Asia*: Vu University Press. 352 pp. ISBN 90–5383–287–4. Price £30.

This is a welcome book because it elevates awareness of environmental issues and research in SE Asia. Up to now books on the environment tend to be characterised by a lack of understanding and knowledge of environmental problems which exist outside N. America and Europe.

The book summarizes a series of research papers given at the '1st international Conference on Environmental Toxicology in SE Asia' held in Indonesia in 1992. Unlike a number of proceedings volumes this book is very well written, well structured and the ilustrations are excellent. The book is divided into 5 parts; challenges of environmental toxicology in SE Asia (basically a series of review articles on environmental management and strategy in SE Asia); pesticide studies; trace metal studies; toxicity tests; environmental assessments (mainly case studies on environmental problems related to specific industries or construction projects). The list of subjects covered in the book is seemingly endless and includes the marine environment, soils and metal contamination, mine waste waters and ecotoxicology. In short it has something for everyone.

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