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EFFECTS OF FOREST EDGES ON THE SOLAR RADIATION REGIME IN A SERIES OF RECONSTRUCTED TROPICAL ECOSYSTEMS

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ABSTRACT

Daily and seasonal light regimes, as a function of position relative to forest edges, were calculated for an 8-hectare forest clearing using hemispherical photography. The study site was located in a tropical wet forest cleared to study ecosystem reconstruction at La Selva Biological Station, Costa Rica (latitude 10° 26' N). More than 200 hemispherical photographs were taken along a series of east-west and north-south transects and analyzed to determine solar radiation regimes using the video image analysis system CANOPY. Results were entered into an ARC/INFO geographical information system. Comparisons of solar radiation isolines demonstrate that the geometry of east and west forest horizons most significantly modify daily solar radiation fluxes, while north and south horizons modify seasonal fluxes. Average daily duration of direct beam solar radiation ranged from 11 hours in the north-central plots to 5 hours in the southernmost plots. This approach can be used to quantify heterogeneity across a broad range of spatial scales.

INTRODUCTION

Boundaries between structurally dissimilar kinds of vegetation have long been known to be zones of biological importance (e.g., Barick 1945, Janzen 1983, Young *et al.* 1987), and recent years have witnessed a resurgence of interest in limits between landscape units. Most studies have focused on the dynamic biological attributes of edges, including their influence on propagule availability (Williams-Linera 1990a), dispersal (Howe 1977), and predation (Lovejoy *et al.* 1986), all of which are important when planning reserves (Janzen 1983).

Edges also influence the abiotic environment of contiguous vegetation (DeWalle and McGuire 1973). Most conspicuously, forests impede the penetration of sunlight into adjacent clearings, and this directly influences photosynthesis (e.g., Chazdon and Fetcher 1984, Fetcher *et al.* 1987). The light regime also has significant impacts on other aspects of microclimate such as humidity and temperature (Wales 1967, Swift and Knoerr 1973, Fritschen 1985), which in turn can affect processes such as transpiration, decomposition, and pollination.

The daily and seasonal flux of sunlight available to ecosystems results, at one scale, from the astronomical factors of earth tilt and rotation. These can be factored into site characterization using the geometries of latitude and time-dependent solar angles (Reifsnyder 1965). At a local scale, however, it is also necessary to consider the impacts of nearby barriers; in this study the barrier was a tropical forest.

At any forest edge, the height of the canopy, the number and size of openings, the distance of openings from the edge, and the orientation of openings relative to the path of the sun all modify the light regime of adjacent landscape units. The edge of a tropical forest, with its diversity of tree species of mixed age classes, subject to branch falls, senescence, and herbivory, is a particularly complex, dynamic barrier. Generating surface models that quantify the impacts of such barriers on adjacent clearings requires techniques that can capture the irregularities of the barrier and interpolate from a sample of data points to an entire surface. Hemispherical photography, used successfully for smaller gaps (Norman and Campbell 1989), can also be used to quantify the effects of horizon barriers. This study was designed to measure and map the daily and seasonal heterogeneity of the potential solar radiation regime on a large clearing in a tropical forest.

STUDY SITE AND METHODS

Study Site

The area of study is an 8 hectare clearing at the Organization for Tropical Studies La Selva Biological Station in Costa Rica (10° 26' N, 32° 59' W); the vegetation of the station is described by Hartshorn (1983). The site (Figure 1) contains plantations (established in 1991) of several species grown in monocultures and in combination, and subjected to various harvest cycles. The plantations are intended to serve as a "outdoor laboratory" for basic ecological research on sustainability and restoration.

The study area is bordered by 30 to 40 m tall forest, except along the northern edge and the northernmost position of the western edge, which are bounded by trees growing along the edge of a steep bank that drops to the Sarapiqui River. There is one small, dense stand of tall bamboo just outside the northwest corner of the clearing.

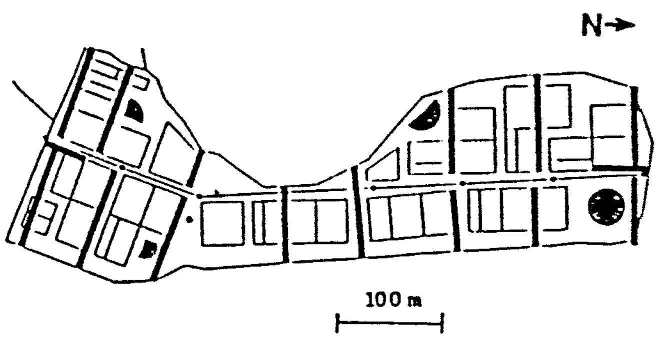

Figure 1. Study site showing the location of 18 research plantations and 16 transects where photographs were taken.

Methods

Because manual surveying techniques are ill-suited for measuring the complex geometry that results from openings between leaves, branches, and trees, we used hemispherical photography (Rich 1990) to characterize sky and edges from 213 points. Photographs were taken at 10 m intervals along 16 transects positioned at right angles to the forest edge (Figure 1). The transects were located so that they would best characterize the light regime of the experimental plantations. Additional photographs were taken every 5 m along portions of the transect closest to the forest edge for a distance equal to the height of the nearest canopy. The photographs were taken within a 5 day period in June 1991 and subsequently digitized and analyzed.

Photographs were taken with a Nikkor 8 mm hemispherical lens mounted on a Nikon FM2 body with MF16 databack at shutter speeds of 125 or greater and using a red filter except when light levels were too low. We used Kodak TMAX 400 film pushed to ASA 800 and developed it in Kodak D76 for 12 minutes at 25° C. The camera was mounted in self-leveling gimbals and positioned 1.5 m above the ground on a monopod. The camera was oriented to magnetic north before taking each photograph to enable us to later overlay the sun track during analysis. Photographs were taken when skies were evenly lit with pre-dawn, post-sunrise, or overcast skies.

The photographic negatives were backlit and video digitized with CANOPY (Rich 1990). Due to the large proportion of open sky in the images, all regions were not evenly exposed. When necessary, digitized images were processed with the video image analysis system IMAGE (Rich *et al.* 1989), which allowed identification and isolation of regions with comparable illumination. A region-specific threshold appropriate to distinguish foliage from openings or clouds was determined, and a composite image of all regions for each photograph was then created.

Each photograph was analyzed with CANOPY to determine the indices of expected solar radiation. CANOPY calculations included 1) the proportion of direct sunlight (direct site factor, DSF) and indirect (i.e., diffuse) skylight (indirect site factor, ISF), 2) DSF for each position as a function of month and time of day, and 3) the hours of direct light received as a function of month. ISF and DSF were calculated both with and without cosine corrections. Calculations of ISF assumed a uniform distribution of indirect light, such that ISF is equivalent to angular area. Our DSF values are not corrected for cloud cover, so they can be interpreted as equivalent to potential duration of direct light. All calculations included corrections for lens distortion. Isoline maps representing hours of direct sunlight were constructed from the December, March, and June CANOPY calculations using the TIN linear method of triangulation on the ARC/INFO Geographic Information System (Environmental Systems Research Institute 1989).

Canopy profiles were constructed from clinometer readings taken at 5 m intervals along 50-m-long lines oriented parallel to the canopy edge. Two east-edge lines were located 47 and 113 m, respectively, from the edge, and two west-edge lines were 50 and 116 m, respectively, from the edge.

RESULTS AND DISCUSSION

The digitized hemispherical photographs (Figure 2) show clearly the increasing influence of the forest closer to the edge of the clearing. Not all forest boundaries, however, have the same impact on incoming sunlight. This is illustrated by the differences between the eastern and western edges of the clearing. Along the densely forested eastern edge an observer sighting to the horizon along a constant bearing tends to target the same point whether at 47 or at 113 m from the edge; thus, the profiles viewed from the two distances are parallel, but the angle of observation is about twice as steep from points at 47 m than at 223 m (Figure 3A). Along the more sparsely vegetated western boundary, on the other hand, the horizon is more distant, so the distance of the observer from the clearing edge has little effect on the angle to the horizon (Figure 3B). Thus, the change of solar energy regimen as a function of distance from the edge is likely to be more marked along the eastern than along the western boundary of the clearing.

That proved to be the case, as illustrated in Figure 4 (upper). Both indirect and direct site factors site factors decline more steeply along the east side of the clearing than along the west side. The same is true when comparing the densely forested south boundary with the more open northern boundary (Figure 4, lower).

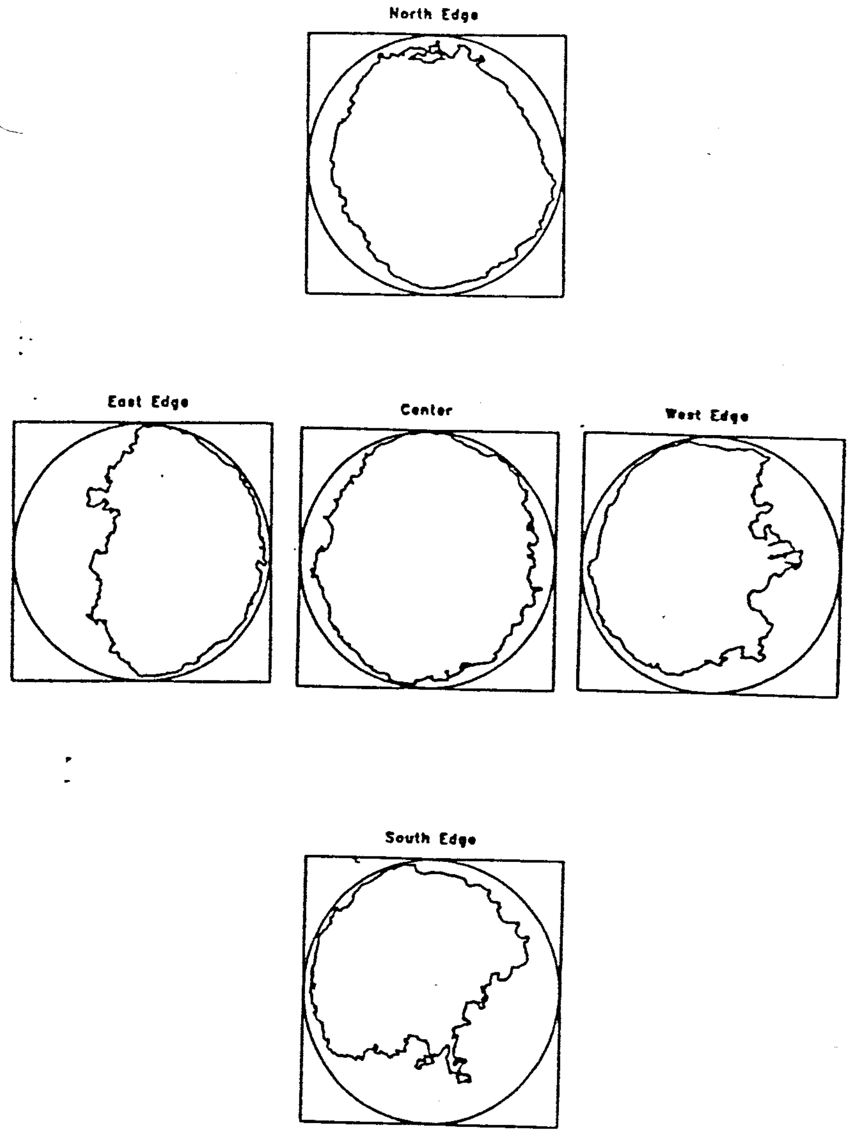

Figure 2. Digitized images of representative hemispherical photographs taken 10 m from the forest edges and near the center of the clearing. East and west are transposed because the photographs represent horizons seen from below.

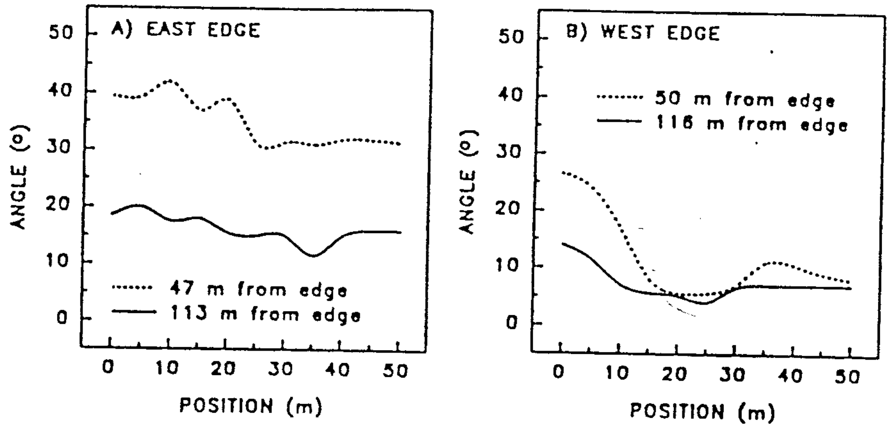

Figure 3. Forest profiles along the A) east and B) west edge of the clearing.

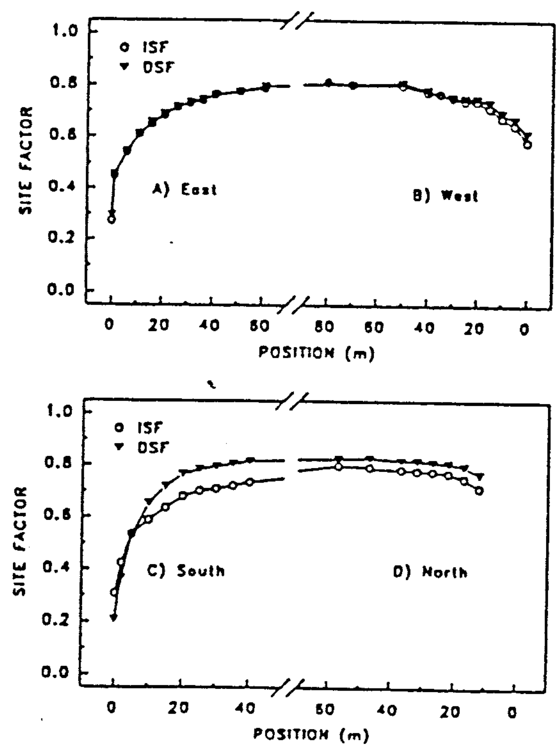

Figure 4. Indirect Site Factor (ISF) and Direct Site Factor (DSF) as a function of distance from the forest edges.

Is it essential to apply the cosine correction to the indirect and direct site factors? Not necessarily, because corrected and uncorrected values tend to be very well correlated (Table 1). Furthermore, the uncorrected values of the direct site value are well correlated from the uncorrected indirect site values (Table 1), particularity when moving perpendicular to the eastern and western edges (Figure 4).

Table 1. Relationships among cosine corrected (C) and uncorrected (U) site factors, and direct and indirect, uncorrected, site factors, n = 264. Values shown are for the coefficient of determination (r^2) and the slope (a) of a linear regression forced through the origin (intercept, b = 0)

SITE FACTOR	r^2	a
ISFU & ISFC	0.98	1.23
DSFU & DSFC	0.98	1.19
ISFU & DSFU	0.96	1.04

The eastern and western edges have important consequences for the daily course of shade cast near the edges of the clearing, but it is the northern and southern edges that have the most dramatic impacts on annual shifts in exposure to direct-beam radiation (Figure 5). At this tropical latitude, both northern and southern edges influence exposure, although the most marked influences occur within 20m of the southern edge, where about twice as many hours of direct sunlight are potentially received on a June day as on one in December.

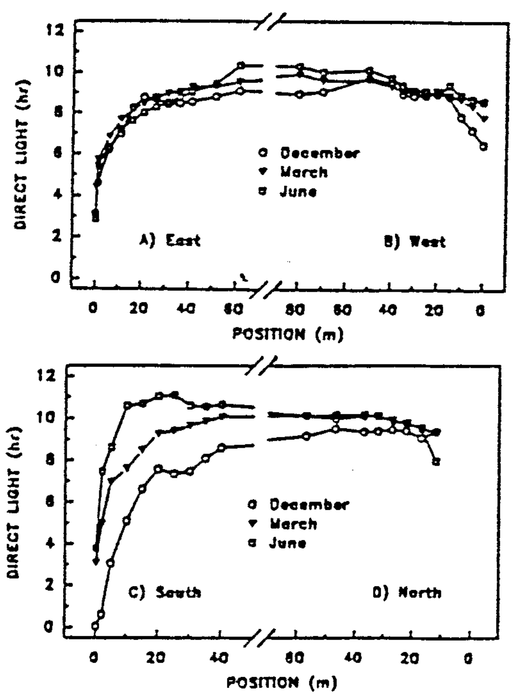

Figure 5. Seasonal changes in hours of direct light.

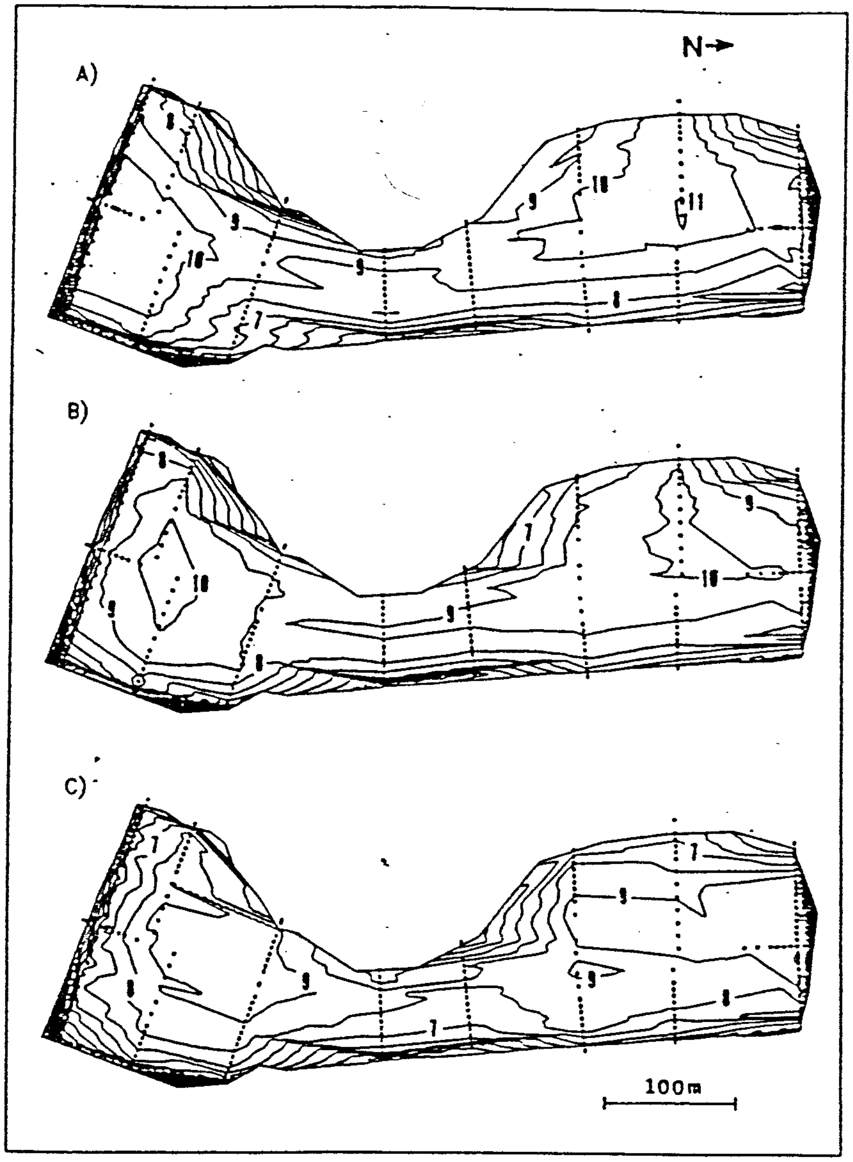

Figure 6. Isolines showing hours of direct beam radiation in the clearing for a) June, b) March, and c) December. Dots show locations of photographs. Contour intervals are 1 hour intervals; areas with insufficient data to generate interpolations are shaded.

Throughout much of the clearing, there is less than a one-hour shift in the duration of direct sunlight from one solstice to another (Figure 6). Most areas potentially receive at least 7, and some places more than 9, hours of direct radiation each day of the year. How will this heterogeneity of solar radiation influence the experimental plantings? Plots were not positioned within the area of greatest forest-edge effect, the zone within 20 m of the forest border, where direct exposure to the sun in one case dropped to 0.06 hours. The north to south axis of the site is also a factor contributing to a relatively homogeneous light regime among plots. Major seasonal effects of the changing solar angle are limited to the relatively small southern portion of the site. Thus, most of the plantations experience a similar light regime of 9 to 10 hours of light in June-July, 8 to 10 hours in March-April, and 7 to 9 hours in December-January.

There are, however, some plots where the light regimes are dissimilar due to daily variation (minimum of 7, maximum of 11 hours) within the same season. Interseasonal extremes are even larger, ranging from 5 to 11 hours.

The maps did reveal some anomalies. For example, some points in the clearing, well removed from the edges, are exposed to fewer hours of direct sunlight in June than in December. This is due to their location with respect to distant tall trees that block direct-beam radiation when the sun arcs north of the clearing. Such unexpected finds would not have been revealed without the sort of detailed image processing involved in producing the maps.

CONCLUSIONS

Heterogeneity of light regimes at a landscape level are the result of interactions between local geometric and landscape forms. Forest edges can exert a significant influence on the solar radiation regime on nearby landscape units. This influence is strongest within a distance from the edge approximately equal to the canopy height. East and west edges act primarily on a daily level because they cast shadows in the morning and evening, respectively. North or south edges act primarily on a seasonal level because they cast shadows more in the summer or winter solstice months, respectively. Hemispherical photography allows a whole sky horizon view of barrier geometry from a particular location and can be used to sample a series of points to construct surface models of expected solar radiation regimes. Although caution must be exercised in interpreting maps constructed by interpolation, the irregular isoline patterns found along the edges of the clearing correlate to the known shape of the boundaries, their barriers, and solar angle.

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