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The effect of incorporating the height of bordering trees on gap size estimations: the case of Argentinean *Nothofagus pumilio* forest.

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Abstract

For forests of *Nothofagus pumilio* (Poepp *et* Endl.) of Chubut province, Argentina, the Forest Office recommends a type of group selection as the system of regeneration. This method involves the creation of gaps in the canopy. Gap size determines seedling recruitment and sapling growth in these forests as a result of dry summers. However, in the context of *N. pumilio* forest management, there is no consensus on the best methodology for gap size measurement and this leads to an inaccurate link between ecological studies and management guidelines. This study aimed to produce an experimental method for determining gap size which may be suitable for both forest management and ecological analysis. The sizes of fourteen artificially created forest gaps were determined under a range of scenarios involving two definitions of gap limit, six calculation methods and using either the gap surface or the ratio between the gap diameter and canopy height. These scenarios were compared based on their correlation with three ecological variables (incident radiation, soil moisture and sapling growth). No differences between gap limit definitions or between calculation methods were found. The use of the gap diameter/canopy height ratio significantly improved the correlation with ecological variables. Also, the correlation between dominant height and soil moisture was better than average height with soil moisture. Based on these results, we propose the use of polygonal expanded gap diameter/dominant canopy height ratio as a gap size parameter for the measurement of gap size in *N. pumilio* forests. This parameter will be applicable to both ecological research and forest management.

Keywords: Group selection, incident radiation, soil moisture, saplings growth, forest management.

Introduction

In forests where broad-scale disturbances are rare or infrequent, forest dynamics is often dominated by the formation and colonisation of canopy gaps (Oliver & Larson, 1996; Veblen, 1992; White & Pickett, 1985). Gaps are created by the fall or death of one or a few canopy trees, producing changes in microclimatic variables (e.g. light, soil humidity and temperature), and facilitating the regeneration of some species (Aussenac, 2000; Collet et al., 2001; Degen et al., 2005; Veblen et al., 1992). Although there is much information about gap dynamics and its influence on forest succession, the link with forest management is quite unexplored for many species (Coates & Burton, 1997). The Patagonian Nothofagaceae *Nothofagus pumilio* (Poepp *et* Endl.) Krasser is a semitolerant species that requires canopy openness to regenerate

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(Veblen, 1989). Even so, seedlings die in the centre and southern portions of large gaps in stands with summer water deficit (i.e. the northeastern zone of *N. pumilio* distribution or stands with northern aspect) (Heinemann & Kitzberger, 2006; Heinemann et al., 2000; Rusch, 1992). The requirements of those saplings that survive may vary as they grow since light is the limiting factor for height growth (Albanesi et al., 2008; Collet et al., 2001; Martinez Pastur et al., 2007; Tabari et al., 2005).

Both light and soil moisture vary with gap size. The conditions at the centre of a large gap are different from those in smaller ones which, in turn, are different from conditions in the surrounding undergrowth. Light and soil moisture also vary within a gap; northern edges are more shady and humid than the centre and southern edges. There is evidence that variation in both light and soil moisture affect seedling recruitment and growth (Albanesi et al., 2008; Gray et al., 2002; Heinemann et al., 2000; Runkle et al., 1995).

In the Chubut province of Argentina, the Forest Office recommends the use of the Group Selection System (GSS) (*sensu* Bava & López Bernal, 2005) to regenerate the forest. This System involves the creation of canopy gaps by felling up to six adjacent adult trees. The overall area occupied by these gaps can reach up to one third of the stand, and the time between harvests is about 35 years. Although there are some guidelines (e.g. Heinemann & Kitzberger, 2006) about the optimal gap size needed for maximum seedling recruitment, there is currently no clear definition of gap size. Also, the effect on light, soil moisture and sapling growth of either creating or enlarging a gap in these forests is not well known.

Not only is the definition of gap size unclear but the definition of a "gap" itself is also open to interpretation which causes confusion. In this study, we examine three key methodological issues (gap limit, calculation method and field method) that need to be considered in order to determine the optimal procedure for determining gap size as an area. We also consider the use of two additional parameter types that incorporate the heights of bordering trees in their calculation. Specifically:

Gap limit: there are two main schools of thought on how to define this parameter. On the one hand, there is the proposal of Brokaw (1982), who defined the gap as a "hole" in the forest that extends across all levels to an average height of two metres above the ground, and whose boundaries are defined as vertical walls. The space calculated by this method is usually called the "canopy gap". However, this method has been criticised because it underestimates the area affected by the gap (Popma et al., 1988). On the other hand, Runkle (1981) proposed the concept of an "expanded gap" whose limits extend to the base of the bordering trees. Runkle argued that this method has the advantage of including the area where light availability is directly and indirectly influenced by the gap.

Calculation method: regardless of the gap type (i.e. the definition of its limits), there are several methods to calculate or estimate the surface of a gap. These methods differ mainly in the degree of form simplification, i.e. how faithfully they capture boundary irregularities, moving from ellipses to polygons, octagons or hexadecagons, either with straight sides or with sections of an ellipse (Brokaw, 1982; Green, 1996; Lima, 2005; Runkle, 1981; Zhu et al., 2009).

Field Method: Finally, different methods, such as measuring directions and distances from the gap centre or the triangles method (Lima, 2005), may be applied to measure the variables needed to calculate gap size. These methods may be more or less effective depending on the characteristics (such as understory density and height) of the forest being studied. The optimal field method must also be evaluated in terms such as its ease of operation, time requirement, necessary tools.

The three issues listed above are all based on the conception of a gap as a surface. The relationship between gap diameter and canopy height has also been used as a reference parameter in some studies (Albanesi et al., 2008; Minckler & Woerheide, 1965; Runkle, 1985), especially where gap creation has been used as a management activity. Canopy height is a parameter with a direct influence on the amount of received radiation. Therefore, the addition of canopy height in any calculation may lead to a significant improvement in the accuracy of gap size estimation. No objective comparison of these methods has been performed to date, however.

The aim of this study is to provide useful information for improved gap management by maximising sapling growth. We did this by assessing a range of scenarios to determine gap size. The correlation of each of these scenarios with three ecological variables (incident radiation, soil moisture and sapling growth) was also calculated. In addition, we evaluated the effect of enlarging a gap on incident radiation in *N. pumilio* forests.

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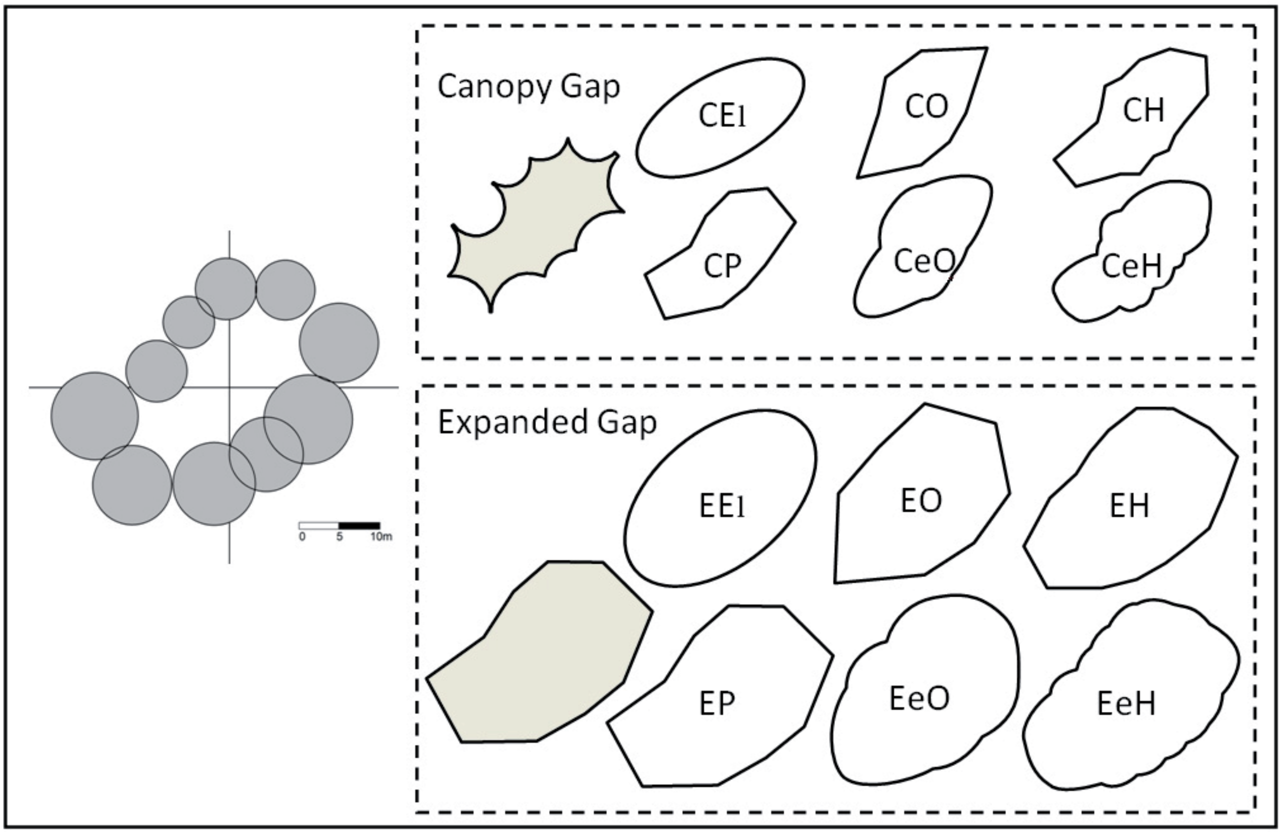

FIGURE 1: *Left-hand side:* a schematic view of a gap with the bordering trees crowns; *Right-hand side:* the schemes used for the analysed gap limits of an actual gap shown in grey - canopy (C) and expanded gap (E) and the six calculation methods: ellipse (El), polygon (P), octagon (O), hexadecagon (H), elliptical octagon (eO) and elliptical hexadecagon (eH). Codes in the figure are the contribution of the gap limit code plus the calculation method code.

Materials and Methods

The study was carried out at a monospecific *N. pumilio* forest called "Huemules", in northwestern Patagonia (42°46' S 71°27' W), between 1100 and 1200 m above sea level. Average annual rainfall is 1100 mm, only 20% of which occurs during spring-summer, mean annual temperature being 6 °C. This forest was slightly highgraded in 1988 by cutting the individuals with the highest timber quality. Due to the presence of stem rot in most larger trees, this involved the felling of only 50 to 70 individuals per ha with a DBH between 35 and 75 cm (approx. 30% of basal area) (unpublished data), and currently shows a two-strata structure with regeneration growing mainly in artificial gaps created during this process. In contrast, unharvested forests are pure stands with an uneven-aged structure, due to a low frequency of broad disturbances and a relatively high frequency of small disturbances produced by the fall of over-mature trees affected by stem rots (Cwielong & Rajchenberg, 1995).

Fourteen gaps of different sizes were selected avoiding those having dead trees or trees fallen after harvest. In each gap, the centre was located using the Runkle (1982) method. From this point, the position, crown projection and total height of each bordering tree was measured, using a compass and a digital hypsometer (Forestor Vertex 80-160, Haglöf AB, Sweden). This instrument allows for easily determining both distance and height of bordering trees, even if the regeneration partially obstructs the vision. With this information, we evaluated the combination of two different definitions of gap limits (canopy and expanded gap), six calculation methods (ellipse, polygon, octagon, hexadecagon, elliptical octagon and elliptical hexadecagon) (Figure 1) and we compared three gap size parameter types: the use of gap area, the use of gap diameter/canopy average height ratio and the use of gap diameter/canopy dominant height ratio. Each of the two gap limit definitions, six calculation methods and three gap size parameter types was applied as follows:

***Gap limits**:*

Canopy Gap (C): land surface area directly under the canopy opening, assuming that gap sides are vertical (*sensu* Brokaw, 1982);

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Expanded Gap (E): area of the polygon formed by bordering tree boles (Runkle, 1981).

Calculation methods:

Ellipse (El; Runkle, 1981): gap area using the formula for an ellipse with length (*L*) equal to the largest distance from edge to edge, and width (*W*) equal to the largest distance perpendicular to the length ($A_{El} = \pi LW/4$);

Octagon (O; Brokaw, 1982): Gap area estimated through an octagon whose vertices are defined by the intersection between eight radial transects distributed by regular angles starting from the North, and the gap border using Equation [1] with n = 8 and $\theta = \pi/4$;

Hexadecagon (H; Green, 1996): Same as octagon but with 16 vertices and using Equation [1] with n = 16 and $\theta = \pi/8$;

Polygon (P; Lima, 2005): Gap area estimated through a polygon using Equation [1] with n = number of bordering trees and θ measured between each pair of bordering trees from gap centre;

Elliptical octagon (eO; Zhu et al., 2009): Gap area estimated as the addition of eight elliptical sectors using Equation [2] with n = 8 and $\theta = \pi/4$;

Elliptical hexadecagon (eH; Zhu et al., 2009): Same as elliptical octagon but with 16 sectors and using Equation [2] with n = 16 and $\theta = \pi/8$.

Equation [1] is defined as:

$$A_{H\ or\ O\ or\ P} = 0.5 \sum_{i=1}^{n} L_{i+1} L_i \ (\sin \theta)$$

Where *A* is the area of octagon, hexadecagon or polygon, *n* is the number of sides, *L* is the length of the radius between gap centre and each corner and θ is the angle between two adjacent radiuses.

Equation [2] is defined as:

$$A_{eH\ or\ eO} = \sum_{i=1}^{n} [ab \arccos (\cos\theta\ L_i\ /\ a)]\ /\ 2$$

with

$$b = \frac{aL \sin\theta}{\sqrt{a^2 - L^2 \cos^2 \theta}}$$

Where *A* is the area of elliptical octagon or elliptical hexadecagon, *a* and *b* are the longest lengths from gap edge to gap edge and the largest width perpendicular to the length of an ellipse, and the other variables are the same as in Equation [1].

Field Method:

This issue can only be subjectively analysed since we performed all necessary measurements for all combinations of gap limits, calculation methods and parameter types in a single moment (i.e. direction and distance from gap centre, bordering trees height).

Gap size parameter types:

Gap area (A): Area (m^2) calculated using each of the six calculation methods;

Diameter/Average Height ratio (D/H_a): Gap diameter (m) calculated from each of the six areas using Equation [3] divided by the average height (m) of bordering trees;

Diameter/Dominant Height ratio (D/H_d): Same as D/H_a but using the average height of the three tallest bordering trees.

Equation [3] is defined as:

$$D_{ij} = \sqrt{A_{ij}\ x\ 4/\pi}$$

Where D_{ij} *is the gap diameter and* A_{ij} is the gap area estimated by combining the gap limit *i* and calculation method *j*.

Incident radiation in gap centre

Five circular subplots (2 m^2) were established in each gap. One subplot was positioned in the centre of the gap and the others were positioned along the cardinal directions at one third of the gap radius (Figure 2). These five subplots characterised both the gap centre and the conditions in which those saplings with the highest probability of reaching the forest canopy were growing (Runkle et al., 1995). In each subplot, one hemispherical photograph was taken using a digital camera (Nikon Coolpix 5400) with a fisheye lens (Nikon FC-E9), mounted on a self-levelling base (Delta-T Devices Ltd, Cambridge, UK) at a height of 2 m. Each image was processed using Gap Light Analyzer software (Frazer et al., 1999) and the resulting parameters (Total (TotR), Direct (DirR) and Diffuse Radiation (DifR)), were averaged for each gap. Using these variables, both correlation (Pearson) and regression analyses between radiation at the centre of the gap and the gap size were carried out.

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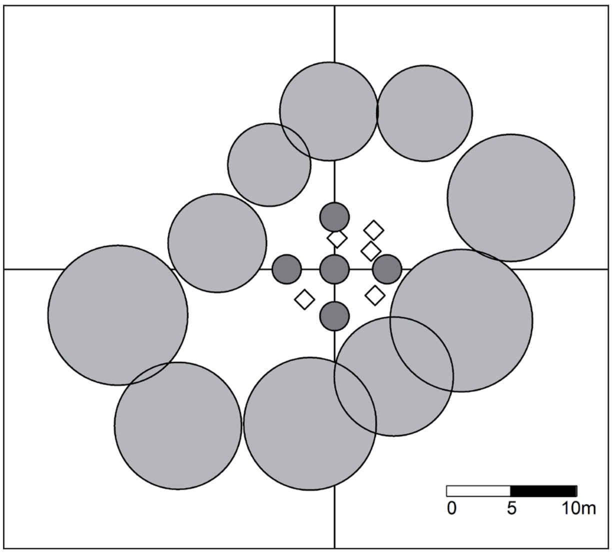

FIGURE 2: Scheme of a gap showing the bordering trees (light grey circles), the five subplots (dark grey circles), and the five tallest saplings (diamonds).

Gap size

Two gap size categories (small or big) were used. These were defined as gaps having a D_{EP}/H_d ratio greater or less than 1, respectively.

Soil moisture in gap centre

In each subplot, soil moisture was measured monthly at two depths (0 – 15 cm and 40 – 55 cm) from November to March of 2006 – 2007 and 2007 – 2008 growing seasons, using an IMKO Trime-FM3 Time Domain Reflectometry sensor (TDR) with a P3Z probe. All gaps were measured on the same day. The effect of gap size on soil moisture was analysed by applying a repeated-measures ANCOVA and its magnitude was quantified through the partial eta-squared value that describes the proportion of total variability attributable to each factor (SPSS Inc., 2006).

Sapling growth in gap centre

A larger sample of 45 gaps was used for the evaluation of the three methodological issues in relation to sapling growth. In each gap, five to ten of the tallest saplings were selected and measured for growth. A total of 350 trees were measured. *Nothofagus pumilio* presents only one growing unit (GU) in each spring – summer period, with its boundaries identified by scars visible to the naked eye (Puntieri et al., 1999), the height growth of each plant sampled could be determined by means of GU length measurement, so the lengths of the last four GUs were measured. The growth data were then averaged for each gap.

Gap age was estimated using a combination of the age of two large saplings (measured from basal cores or slices) and the changes in radial increment rates of border trees (measured from incremental cores).

The effect of gap size on sapling growth was quantified by regression analysis using both linear and the most usual (logarithmic, inverse, quadradic, cubic, power, S-curve, growth and exponential) transformation models(SPSS Inc., 2006).

Effect of gap enlargement

To analyse the effect of gap enlargement on incident radiation, five gaps were enlarged by felling some border trees in autumn 2007. Light and soil moisture measurements described above were taken before and after the enlargement. The effects were compared by running Pearson's correlations.

Results

Evaluation of methodological issues

The areas calculated using canopy and expanded gap methods ranged between 23 and 675 m^2 and between 73 and 1080 m^2 respectively. Variations among calculation methods ranged between 8% and 53% for canopy gaps and between 14% and 36% for expanded gaps. As expected, all gap size parameters were highly correlated with radiation measurements. However, a poor correlation with soil moisture and an acceptable fit with sapling growth were found (Table 1).

If we independently compare the fit of the gap limit types, the calculation methods and the parameter types with the diffuse radiation availability, we can observe that the gap limit type does not have a remarkable influence, all calculation methods except ellipse have a similar performance and that incorporating canopy height (any of both) on gap size parameter shows a 15% average improvement on Pearson's r values. A similar result was observed for soil moisture and sapling growth (Figure 3).

Although the assessment of the field application of each method was not an objective of this study, there are some observations that can help to evaluate them subjectively. Measuring gap size through methods which consider the position of all bordering tree boles or crowns requires a larger number of measurements than where an elliptical or octagonal shape is assumed. However, they are more objective, and less training and time are required to define their limits, comparing with either the axis of the ellipse or the regularly distributed angles of octagons or hexadecagons, especially for irregularly shaped gaps. On the other hand, measurement of bordering tree

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TABLE 1. Correlations between gap size methodological issues (gap limits, calculation methods and parameter types) and ecological variables (incident radiation, soil moisture and sapling growth).

Parameter type	Calculation Method	Author	Gap limits							
			Canopy Gap (C)				Expanded Gap (E)			
			Code	Incident radiation	Soil moisture	Sapling Growth	Code	Incident radiation	Soil moisture	Sapling growth
Gap area (A) [m²]	Ellipse (El)	Runkle, 1981	A_{CEI}	0.739**	0.300	0.642*	A_{EEI}	0.694**	0.247	0.596
	Octagon (O)	Brokaw, 1982	A_{CO}	0.709**	0.318	0.555	A_{EO}	0.733**	0.332	0.534
	Hexadecagon (H)	Green, 1996	A_{CH}	0.746**	0.329	0.522	A_{EH}	0.730**	0.377*	0.532
	Polygon (P)	Lima, 2005	A_{CP}	0.753**	0.313	0.540	A_{EP}	0.735**	0.354	0.555
	elliptical Octagon (eO)	Zhu et al., 2009	A_{CeO}	0.736**	0.305	0.538	A_{EeO}	0.746**	0.324	0.517
	elliptical Hexadecagon (eH)	Zhu et al., 2009	A_{CeH}	0.750**	0.326	0.527	A_{EeH}	0.734**	0.366*	0.528
Gap diameter/ average canopy height ratio (D/Ha)	Ellipse (El)		D_{CEI}/H_a	0.781**	0.354	0.709*	D_{EEI}/H_a	0.756**	0.339	0.715*
	Octagon (O)		D_{CO}/H_a	0.881**	0.371*	0.641*	D_{EO}/H_a	0.865**	0.371*	0.674*
	Hexadecagon (H)		D_{CHA}/H_a	0.889**	0.401*	0.630	D_{EHA}/H_a	0.846**	0.428*	0.697*
	Polygon (P)		D_{CP}/H_a	0.862**	0.386*	0.645*	D_{EP}/H_a	0.853**	0.406*	0.702*
	elliptical Octagon (eO)		D_{CeO}/H_a	0.885**	0.376*	0.627	D_{EeO}/H_a	0.874**	0.369*	0.659*
	elliptical Hexadecagon (eH)		D_{CeHA}/H_a	0.885**	0.398*	0.632	D_{EeHA}/H_a	0.846**	0.419*	0.691*
Gap diameter/ dominant canopy height ratio (D/Hd)	Ellipse (El)		D_{CEI}/H_d	0.800**	0.412*	0.708*	D_{EEI}/H_d	0.762**	0.392*	0.703*
	Octagon (O)		D_{CO}/H_d	0.872**	0.406*	0.619	D_{EO}/H_d	0.860**	0.444*	0.663*
	Hexadecagon (H)		D_{CH}/H_d	0.887**	0.430*	0.603	D_{EH}/H_d	0.844**	0.491*	0.668*
	Polygon (P)		D_{CP}/H_d	0.859**	0.424*	0.620	D_{EP}/H_d	0.849**	0.472*	0.680*
	elliptical Octagon (eO)		D_{CeO}/H_d	0.876**	0.403*	0.600	D_{EeO}/H_d	0.868**	0.438*	0.648*
	elliptical Hexadecagon (eH)		D_{CeH}/H_d	0.883**	0.427*	0.605	D_{EeH}/H_d	0.845**	0.484*	0.664*

* Significant correlations at a 0.05 level. ** Significant correlations at a 0.01 level.

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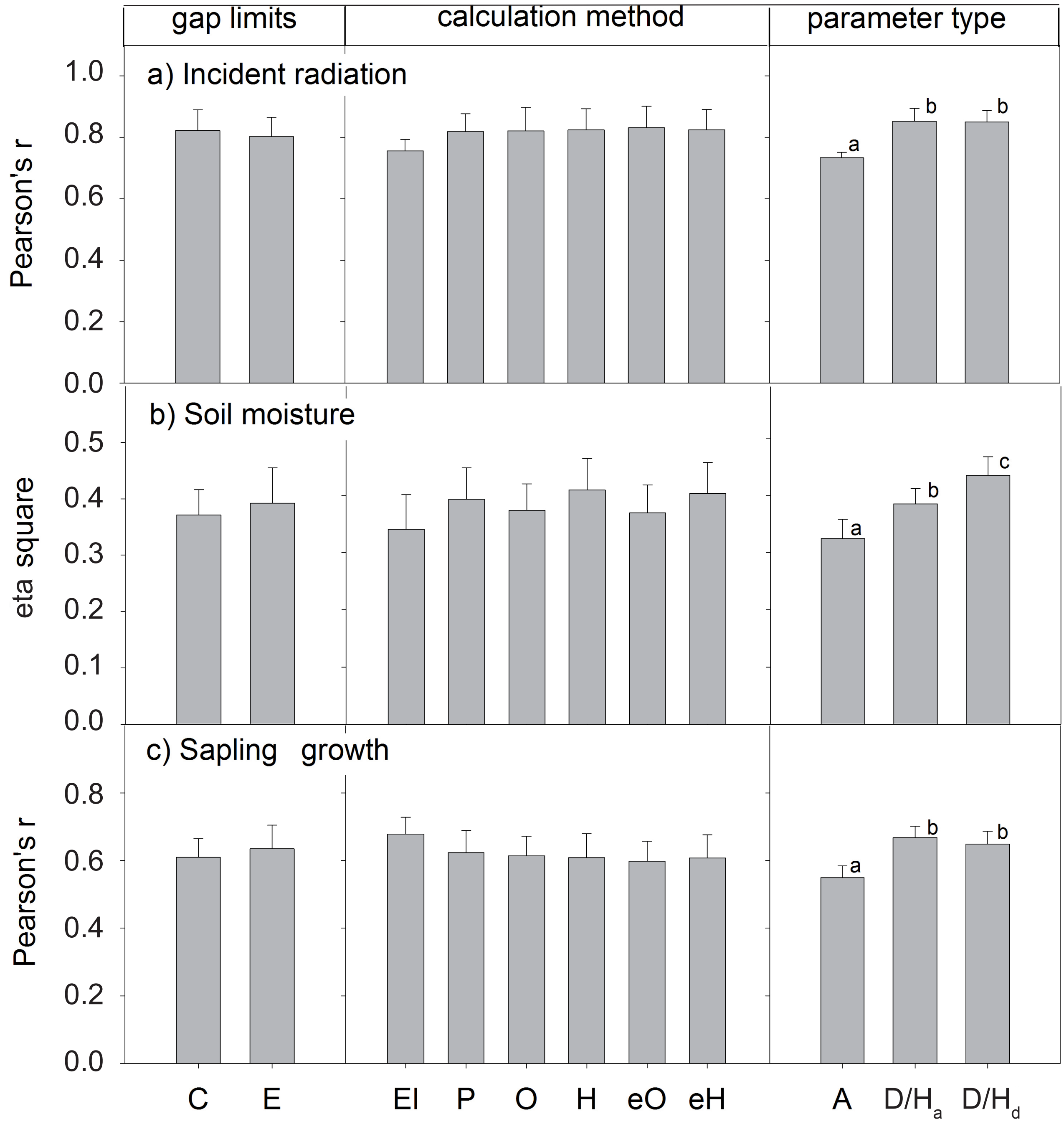

FIGURE 3: Average correlations between gap size methodological issues (gap limits, calculation methods and parameter types) and ecological variables (incident radiation, soil moisture and sapling growth). Abbreviations along the x axis are: Canopy gap (C), Expanded gap (E), Ellipse (El), Polygon (P), Octagon (O), Hexadecagon (H), elliptical Octagon (eO), elliptical Hexadecagon (eH), gap Area (A), gap Diameter/average canopy Height ratio (D/H_a) and Diameter/dominant canopy Height ratio (D/H_d). For gap limits and calculation method no significant differences were found. For parameter type, different letters mean significant differences ($p < 0.05$).

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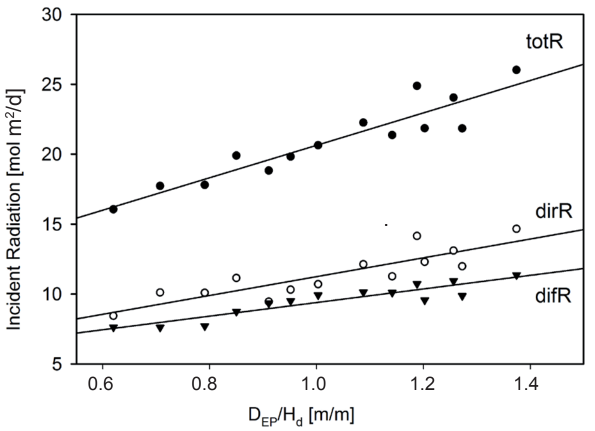

Regression function	AdjR²	SEE	p
totR = 9.043 + 11.596 D_{EP}/H_d	0.857	1.077	< 0.001
dirR = 4.506 + 6.737 D_{EP}/H_d	0.745	0.891	< 0.001
difR = 4.528 + 4.865 D_{EP}/H_d	0.834	0.493	< 0.001

FIGURE 4: Scattered plots and regression analysis for Total, Direct and Diffuse Radiation (TotR, DirR and DifR) and the Expanded Gap Diameter/dominant Height ratio (D_{EP}/H_d).

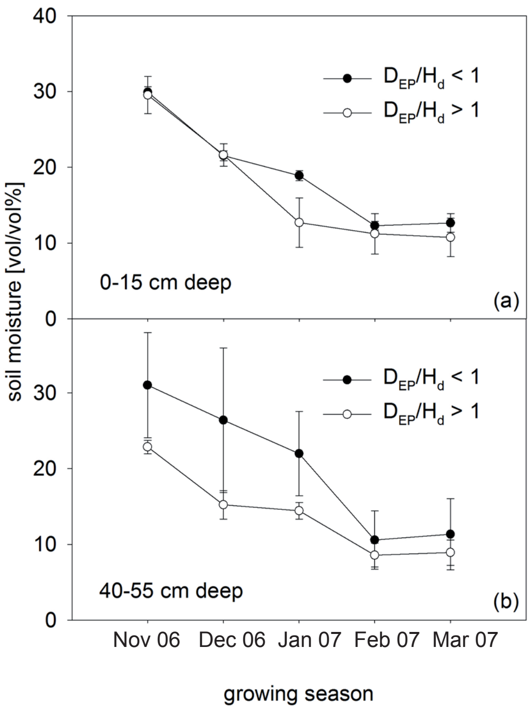

FIGURE 5: Soil moisture levels during the 2006 – 2007 growing season at 0 – 15 cm deep (a) and 40 – 55 cm deep (b), for small gap centres (D_{EP}/H_d < 1) and large gap centres (D_{EP}/H_d > 1).

heights for diameter/height ratios takes a considerable extra time, although the delay is shortened by using a digital hypsometer or a similar device.

Optimal method

Based on the above results and the operational aspects of each method, we selected the combination of expanded gap limits, polygon method and gap diameter/height dominant parameter (i.e. D_{EP}/H_d) as the gap size estimator. In our study site, this parameter showed a strong linear relation with the total, direct and diffuse incident radiation (Figure 4). The various methods have different costs associated with them. Analysis of the most cost-effective method was outside the scope of this study.

At both measured soil depths, soil moisture decreased as the 2006 – 2007 growing season progressed (p = 0.002 and p = 0.032 for the linear and fourth order components at 0-15 cm deep: and p = 0.003 and p = 0.037, for the linear and cubic components at 40-55 cm deep) (Figure 5). The D_{EP}/H_d ratio showed a significant effect on soil moisture (p = 0.019, η^2 = 0.472) mainly at 40 – 55 cm with more humid soils in smaller gap centres. Moreover, the sapling growth best fit was with the sigmoid function ICAh = exp(3.767 – 0.634/(D_{EP}/H_d)) (Figure 6, R^2 = 0.271; p < 0.001).

When comparing the changes caused by both gap enlargement on the gap size estimation methods and the changes of incident radiation in the gap centre, we found that the incorporation of dominant height again improved the fit (Figure 7).

Discussion and Conclusions

The range of gap sizes analysed was similar to previous studies in *N. pumilio* and other similar forests (e.g. Diaci & Kozjek, 2005; Fajardo & Graaf, 2004; Weiskittel & Hix, 2003), and covered the range of gap size previously suggested for the implementation of a group selection system for this species (Berón, 2003).

Evaluating their correlation with incident radiation, soil moisture and regeneration growth, there were no significant differences between different gap limits definitions or calculation methods, except for a slight trend toward lower accuracy using the method of calculation based on an ellipse. This is probably due to the fact that an increment on gap surface calculation accuracy cannot result in a better prediction of the ecological variables studied because other factors come into play. For instance, the height of the canopy was shown to be an important factor that improves the fit between the gap size and the most important micro-

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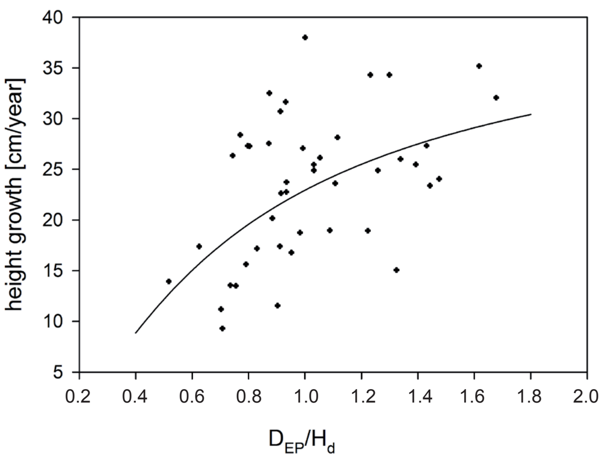

FIGURE 6: Sapling height growth versus Expanded Gap Diameter(m)/dominant bordering trees Height (m) ratio (D_{EP}/H_d).

environmental variables (i.e. incident radiation and soil moisture), which is reflected in an improvement in predicting sapling growth. There are probably other variables, such as forest structure, gap age or soil depth that also influence these relationships.

The Polygonal Expanded gap Diameter/dominant canopy Height ratio (D_{EP}/H_d) is an expeditious method to characterise gap size which allows not only the incident radiation to be estimated but also gaps of different stands and even different species to be compared (Albanesi et al., 2008; Ontario Ministry of Natural Resources, 2004). This method also incorporates dominant canopy height, which improves gap characterisation at different sites. A range for this variable is between 14 and 30 m, and makes D_{EP}/H_d an adaptable parameter. The strong correlation between D_{EP}/H_d and incident radiation makes this parameter a good radiation predictor for gaps in a broad range of gap sizes, and with canopies of different heights, and represents a useful tool, both to define silvicultural guidelines and to carry out forest ecology studies. However, the fitted equations in this study are only indicative since they have been done for a single site.

This method also allowed for the effect of gap size on soil moisture and sapling growth to be evaluated. Moreover, for forest management purposes, parameters that incorporate the position or distance between tree boles not only improve accuracy but also improve the relationship with other important variables such as number of trees per hectare or average distance, including areas directly and indirectly affected by canopy opening (Popma et al., 1988; Runkle, 1982).

The results show that gap size does not have major influence on soil moisture in the centre of a gap with advanced regeneration, while the growth of saplings is greater at higher values of D_{EP}/H_d. The D_{EP}/H_d ratio is an effective parameter for gap size measurement in *N. pumilio* forests due to its high correlation with incident radiation. Also, it is simple and had proved to be efficient in other ecological studies (Albanesi et al., 2008; Aussenac, 2000; Gray et al., 2002; Stewart et al., 1991). Thus, D_{EP}/H_d can be used to define management guidelines framed in the Group Selection

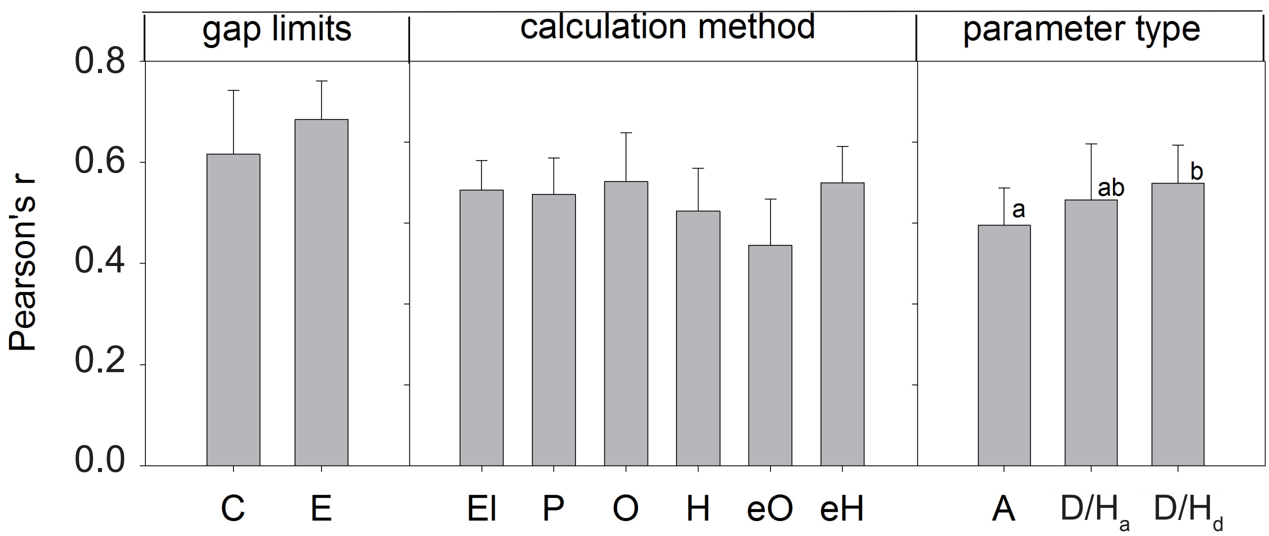

FIGURE 7: Average correlations between gap enlargement evaluated by different methodological issues (gap limits, calculation methods and parameter types) and changes in incident radiation. Symbols of x axis are the same as for Figure 3). For gap limits and calculation method no significant differences were found. For parameter type, different letters means significant differences ($p < 0.05$).

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System used at the analysed site. Based on these results, we suggest the following gap management regime: an initial intervention for seedling establishment consisting of opening gaps with an D_{EP}/H_d value of 1 followed by an enlargement of these gaps made when saplings reach one metre height or more, reaching a D_{EP}/H_d value near 2.

The D_{EP}/H_d could also be used to define guidelines for other group selection systems, based on the light requirements of saplings and the dominant canopy height for canopy gap creation and enlargement.

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