RESPONSE OF *Nothofagus betuloides* (MIRB.) OERSTED TO DIFFERENT THINNING INTENSITIES IN TIERRA DEL FUEGO, ARGENTINA

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SUMMARY

Forestry in Argentina and Chile has been largely developed based on the culture of exotic species, while native species occupied a second place in the national forest policies of research and development. Nothofagus *forests are the main wood resource for the sawmill industry in Tierra del Fuego. Many antecedents of intermediate treatment schedules and thinning trials have been reported, but few of them are in* N. betuloides. *The aim of the present work was to determine the growth and forest dynamics of a young stand, and evaluate the growth responses to three thinning levels, comparing them with an unthinned stand along six years. The 46 year old unthinned stand had a DBH increment of 0.1 to 0.2cm/yr, a volumetric increment of 6.3m³/ha·yr and a natural self-thinning of 350 trees/yr. This stand responded positively to different thinning levels. The DBH increment reached 0.52cm/yr in the high thinning intensity treatment (2000 stems/ha), diminishing in proportion when the thinning intensity decreased (0.37cm/yr and 0.31cm/yr for treatments of 3500 stems/ha and 5000 stems/ha). Less intensive thinning treatment showed the highest volume growth (13.6m³/ha·yr) as compared with the higher intensity (9.5 m³/ha·yr). From the obtained growth and the behavior of the species to intensive silvicultural treatments,* Nothofagus betuloides *is a species of high potentiality in order to be incorporated within a forest intensive management.*

RESUMEN

El sector forestal de Argentina y Chile se ha desarrollado principalmente sobre la base del cultivo de especies exóticas, ocupando el bosque nativo un lugar secundario en la definición de políticas de investigación y desarrollo. Los bosques de Nothofagus *conforman la totalidad del recurso maderero para los aserraderos en Tierra del Fuego. Existen numerosas propuestas de manejo mediante la aplicación de tratamientos intermedios y de ensayos de raleo, pero muy pocas en* N. betuloides. *Los objetivos de este trabajo fueron determinar el crecimiento y la dinámica forestal de un rodal joven, y evaluar las respuestas del crecimiento a tres niveles de raleo, comparándolas con las de un rodal no intervenido a lo largo de seis años. El rodal sin intervención de 46 años de edad tuvo un incremento diamétrico de 0,1 a 0,2cm/año, un incremento volumétrico de 6,3m³/ha·año y un autoraleo natural de 350 árboles/año. Este bosque respondió favorablemente a la aplicación de distintos niveles de raleo. El incremento en diámetro alcanzó los 0,52cm/año en el tratamiento más intenso (2000 individuos/ha), disminuyendo en proporción a medida que la intensidad del raleo decreció (0,37cm/año y 0,31cm/año para los tratamientos de 3500 individuos/ha y 5000 individuos/ha). En contraposición, la menor intensidad de raleo presentó los mayores incrementos volumétricos (13,6m³/ha·año) comparados con la mayor intensidad (9,5m³/ha·año).* Nothofagus betuloides *es una especie con un gran potencial para ser incorporada dentro de un manejo forestal intensivo, por los crecimientos que presenta y la respuesta a los tratamientos intermedios.*

Introduction

Forestry in Argentina and Chile has been largely developed based on the culture of exotic species (mainly *Populus*, *Salix*, *Pinus* and *Eucalyptus*; Navarro *et al.*, 1997), displacing in importance the management of the native forest. For this reason, native species occupy a second place in forest policies of research and development. The main reason for the culture of exotic species is based on criteria of high growth and simple silviculture. In contrast, for the native species, there is a generalized concept of low growth and complex silviculture, their management being difficult under traditional practices.

In Tierra del Fuego, Argentina, introduction of exotic species was tried out (Cozzo *et al.*, 1967, 1969), but with-

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RESUMO

O setor florestal da Argentina e Chile tem-se desenvolvido principalmente sobre a base do cultivo de espécies exóticas, ocupando, o bosque nativo, um lugar secundário na definição de políticas de investigação e desenvolvimento. Os bosques de Nothofagus *conformam a totalidade do recurso madeireiro para as serrarias em Tierra del Fuego. Existem numerosas propostas de direção mediante a aplicação de tratamentos intermédios e de ensaios de raleo, mas muito poucos em* N. betuloides. *Os objetivos deste trabalho foram determinar o crescimento e a dinâmica florestal de um rodal jovem, e avaliar as respostas do crescimento a três níveis de raleo, comparando-as com as de un rodal não interditado ao longo de seis anos. O rodal sem intervenção de 46 anos de idade teve um incremento diamétrico de 0,1 a 0,2cm/ano, um incremento volumétrico de 6,3m³/ha·ano e um autoraleo natural de 350 árvores/ano. Este bosque respondeu favoravelmente à aplicação de diferentes níveis de raleo. O incremento em diâmetro alcançou os 0,52cm/ano no tratamento mais intenso (2000 individuos/ha), diminuindo em proporção a medida que a intensidade do raleo decresceu (0,37cm/ano e 0,31cm/ano para os tratamentos de 3500 indivíduos/ha e 5000 indivíduos/ha). Em contraposição, a menor intensidade de raleo apresentou os maiores incrementos volumétricos (13,6m³/ha·ano) comparados com a maior intensidade (9,5m³/ha·ano).* Nothofagus betuloides *é uma espécie com um grande potencial para ser incorporada dentro de uma direção florestal intensiva, pelos crescimentos que apresenta e a resposta aos tratamentos intermédios.*

out good results, being the spontaneous old growth *Nothofagus* Blume forest the main wood resource for the sawmill industry (Martínez Pastur *et al.*, 2000). The Argentina sector of Isla Grande of Tierra del Fuego has 712000ha of forests of *Nothofagus* genera (Collado, 1999): *N. pumilio* (Poepp. et Endl.) Krasser, *N. betuloides* (Mirb.) Oersted and *N. antarctica* (Forster f.) Oersted.

N. betuloides, commonly named *coihue de Magallanes* in Chile or *guindo* in Argentine (Moore, 1983), is a shade-intolerant species that presents cycles of gap regeneration. It is common to find groups of saplings where a tree fell. In harvested areas, windthrows or areas affected by fire, homogeneous groups of saplings can be found conforming a secondary forest. The established regeneration constitutes the initial stage in the following development of a future stand. Two variables define the initial regeneration: density and spatial distribution. These factors have great importance in growth, development and structure of the future stand, as the competition level between individuals defines the stem form (rectitude and branching; Schmidt *et al.*, 1979). The application of intermediate treatments in secondary forest aims at the regeneration, improving stem quality, stock density and growth characteristics within a developing stand (Daniel *et al.*, 1982). These selective cuts were carried out to correct the negative characteristics of unmanaged forests and increase the quality in wood production (Hawley and Smith, 1982).

Many antecedents of intermediate treatment schedules (Rechene and Gonda, 1992, Fernández *et al.*, 1997) and thinning trials for *Nothofagus* have been reported (Groose, 1987, 1989; Donoso, 1988; Espinosa *et al.*, 1988; Nuñez and Vera, 1992; Rubilar, 1992; Donoso *et al.*, 1993, 1995; Schmidt and Caldentey, 1994; Schmidt *et al.*, 1995, 1996; Peri *et al.*, 2000; Martínez Pastur *et al.*, 2001; Monelos *et al.*, 2001; Donoso and Nirkos Gutiérrez, 2001). However, there is little information about silvicultural treatments in *N. betuloides* (Martínez Pastur *et al.*, 1997a; Vukasovic *et al.*, 2001). The aim of this work was to determine the growth and forest dynamic of a young 46 year old stand, and evaluate the growth responses to three thinning levels, compared to an unthinned stand.

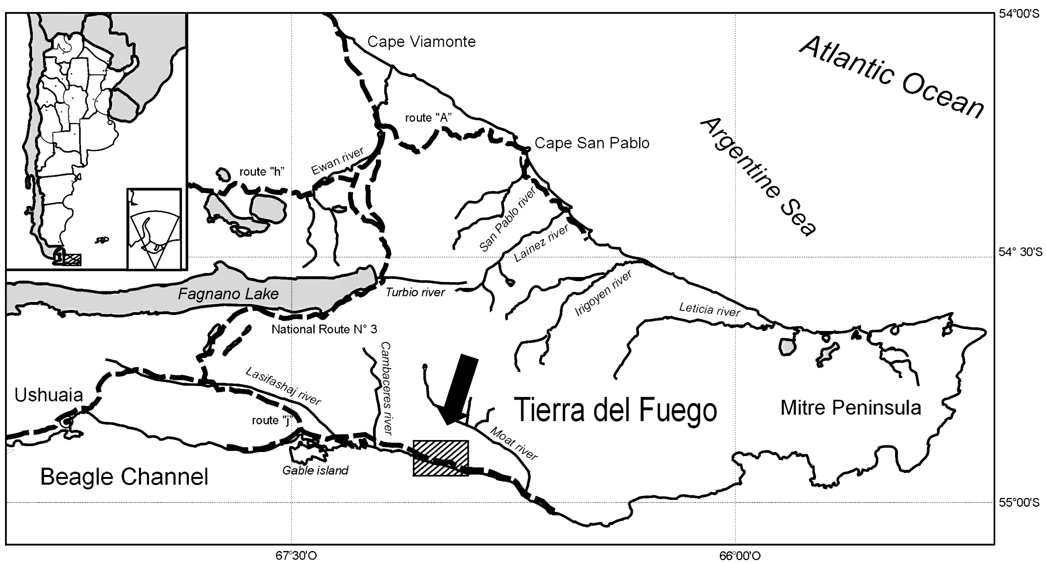

Figure 1. Location of the study area.

Materials and Methods

Study area

Trials were conducted on a pure even-aged *N. betuloides* stand. This forest stand was originated after a fire in 1949, in the eastern zone of the Moat Ranch (54º54'S, 67º08'W; Figure 1) that affected 205ha (Juan and Fernández, 1967), eliminating completely the high tree stratum.

Landscape, soils and climate

The general configuration of the land is irregular with high slopes. Homogeneous and continuous large forests are located on the hillsides of the No-Top hill (824masl) that descend toward the Beagle Channel coasts. The landscape alternates with pet-bogs and wetlands (Juan and Fernández, 1967). The predominant soils are acids, of "*mohr* or *modder*" type, with an upper horizon formed mainly for abundant organic material proved by the trees. This soil has an elevated cationic exchange capacity and low percentage of base saturation (Frederiksen, 1988; Richter and Frangi, 1992). Trees have a superficial radicular system, which does not penetrate in the non-edaphizadic regolits (Juan and Fernández, 1967).

The studied sector belongs to the climatic region of the cold Patagonia (Juan and Fernández, 1967), into the humid climatic zone (Frederiksen, 1988). There is no continuous climate data on the study area (Harberton Ranch 1906-1916 and Puerto Almanza 1953-1956). For this reason the Ushuaia city, 74km away, data was used (Iturraspe *et al.*, 1989). The area possesses a large marine influence, with permanently clouded days and great humidity. The average temperatures of the summer months varies between 4 and 15ºC, while in the winter months it varied between -3 and 6ºC. Another characteristic is the absence of a free-freezing season. The predominant winds are from the SW, with an annual average speed of 6 to 7km/h and a maximum of 200km/h during storm days. The average annual rainfall is 530mm/yr, homogeneously distributed through the year. The snowfall is abundant and covers the forest floor from May to September, with an average snow precipitation of 161mm/yr. The floor freezes during the winter months (May to August) up to less than 1m.

TABLE I
DASOMETRIC CHARACTERISTICS OF THE STUDIED FOREST BEFORE THE CUTTING

Forest structure variables	Average	Standard deviation	Frequency distribution DBH (cm)	Trees/ha
DBH	6.21 cm	0.77 cm	<2.5	340
Total height	8.29 m	0.78 m	2.6-5.0	5060
Density	12700 trees/ha	1029 trees/ha	5.1-7.5	3900
Basal area	49.48 m²/ha	8.77 m²/ha	7.6-10.0	1940
Total volume	337.18 m³/ha	68.9 m³/ha	10.1-12.5	1040
			12.6-15.0	400
			>15.1	20

DBH: Diameter at breast height.

Forest structure and volume estimation

The study area was divided into 16 plots of 100m² each. Four of these plots were randomly chosen, in order to characterize the forest structure of the stand by measuring the diameter at 1.3m of height (DBH) and the total height (H) of all the trees. Thirty trees in the diameter range of 2.8 to 15.5cm were used to fit a total over bark volume equation. The volume of the sample trees was calculated using Smalian formula, every 0.5m from the stump (0.1m) up to 1cm in diameter. Finally, tree-ring analysis was carried out in 60 dominant crown class trees along the diameter range to evaluate DBH growth since the saplings of the stand were established and reached 1.3m height.

Thinning treatments

In November 1993, a random block trial was conducted with four treatments (unthinned, 5000, 3500 and 2000 stems/ha) with three replicates, in a homogeneous area of 1200m² without presence of living parent trees. A 400m² of unthinned stand was left as a control treatment. Thinning from below was carried out, leaving the best specimens and respecting an equivalent distance between them. Trees were chosen when the stem was straight, without excessive branching, healthy appearance, a big well-developed crown, avoiding the presence of *Cyttaria* spp and *Misodendrum* Banks ex DC spp. on the stem. The thinning levels were defined according to the silvicultural management model proposed by Fernández *et al.* (1997) for *N. pumilio*, due to the fact that there are no antecedents for the studied species. The DBH perimeter was measured with a dendrometric tape in all treatments, each winter. However, the mortality and crown class in the unthinned treatment were measured once in a period of four years. For this purpose the trees were identified and the location of DBH measures was marked.

Statistical analysis

Non-linear regression techniques were used to fit the total over bark volume equation based on the methodology previously reported (Peri *et al.*, 1997). The statistic validity of the results was obtained through the analysis of variance by Fisher and Tukey multiple range tests. In the thinning treatments, twenty trees were selected to be measured in each replicate. The significance level used was $P \leq 0.05$.

Results

Total volume equation

The model developed for the estimation of total over bark volume (TOBV) is a local equation that utilizes the DBH as independent variable, based on a simplification of the Schumacher and Hall (1933) model, which was selected for the adjustment of their statistics and the biological behavior of the function. The equation and statistics obtained were

$$TOBV(m^3) = 0.00037605 * DBH(cm)^{2.17940559}$$

$r^2 = 0.96$

$F = 1799.0\ (P < 0.01)$

Residual standard deviation = 0.00912 m³

Forest structure of the original stand

The dasometric values of the studied forest (Table I) correspond to a full stocking stand in optimum initial growth phase development, according to the *N. pumilio* classification proposed for Schmidt and Urzúa (1982). The forest structure has desirable characteristics for the first silvicultural cut: adequate diameters and heights (DBH of 6cm and H of 8.3m), an over stocked stand (basal area of 49m²/ha) with a high density of trees (12700 trees/ha), an initial growth development phase, and good natural pruning with up to 6m clean portion of the stem without large branches in dominant crown class trees. On the other hand, the average diameter growth of the dominant class crown trees (Figure 2) reached a maximum at 22-25yr old (0.3cm/year), after which the growth rate begins to fall.

Forest dynamics in the unthinned treatment

The control plot showed a DBH increment between 0.1 to 0.2cm/yr (Figure 3), being possible to find individual increments up to 05cm/yr. The mean individual increments of basal area and total over bark volume were lower than those obtained in the thinned treatments. The basal area increment of the stand was 1.2-1.4m²/ha·year, being negative in some periods due to the high self-thinning mortality of the trees. The volumetric net increment of the stand for the studied period was 6.3m³/ha·yr, reaching a maximum of 10.8m³/ha·yr (Table II).

Mortality in the control treatment represented the nor-

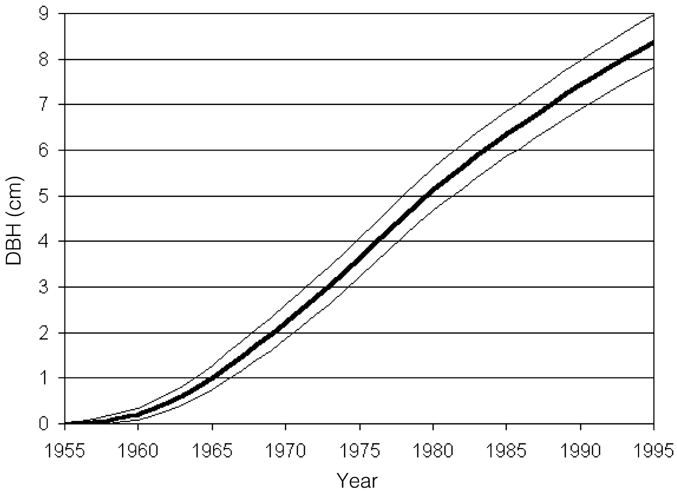

Figure 2. Average diametric growth of the dominant crown class trees in the sampled stand before the thinning treatments application. DBH: Diameter at breast height. Limits using ‘t´ test were done at P <0.05.

mal evolution of a fully stocking stand with an annual mortality of 350 trees/yr (11700 to 10300 trees/ha over 4 years), corresponding to the lower crown classes (50% suppressed trees and 50% intermediate trees). The number of dead trees represented 1.7 to 9.6% of the total number of the individuals in the stand. The DBH of the dead trees varied between 2.4 and 5.0cm. This mortality represented a removal of 0.09 to 1.86m²/ha·yr of basal area (Table II).

The DBH frequencies in the studied plot followed a normal distribution (Figure 4a). After 3 years, this frequency distribution was displaced toward the right and decreased in magnitude, which represented the growth and mortality dynamic of the unthinned stand. The crown classes also varied significantly after the 4 year period (Figure 4b). The mortality occurred mainly in trees of the lower crown classes. Some trees changed their crown classes, from the upper classes to the lower classes. When mortality was expressed as percentage of specimens in the stand, it was observed that the suppressed trees incremented their values compared with the previous measurement. In contrast, the upper crown classes decreased the percentage of trees. This implies that the stand dynamics did not reach equilibrium, and a high rate of mortality is expected in the following years.

Thinning responses

Thinned plots did not register losses due to snow or wind damage during the study. The trial took place near the shores of the Beagle Channel, in a place with high wind exposure, but the thinning assay was small and well protected by the remnant untreated areas around the plots.

N. betuloides trees responded positively to all thinning levels. Higher diameter average growths (0.52cm/yr) were obtained in the high thinning intensity treatment (2000 stems/ha) at the second year of assay, diminishing in proportion to the decrease in thinning intensity (0.37cm/yr and 0.31cm/yr for treatments of 3500 and 5000 stems/ha, respectively; Figure 3a). The same response was obtained when the individual growth of basal area and total over bark volume were analyzed (Figure 3b, c), obtaining the maximum increments at the second year for a thinning intensity of 5000 stems/ha and at the third year for the other treatments.

Significant differences were found when the thinning level was subjected to an analysis of variance for the three studied variables (Table III). There were differences in volume growth one year after the silvicultural treatment. The less intensive thinning treatment showed the highest volume growth (13.6m³/ha·yr) compared with the higher intensity (9.5m³/ha·yr at 2000 stems/ha treatment; Figure 5b). Volume growth also had significant differences in the second year after the thinning

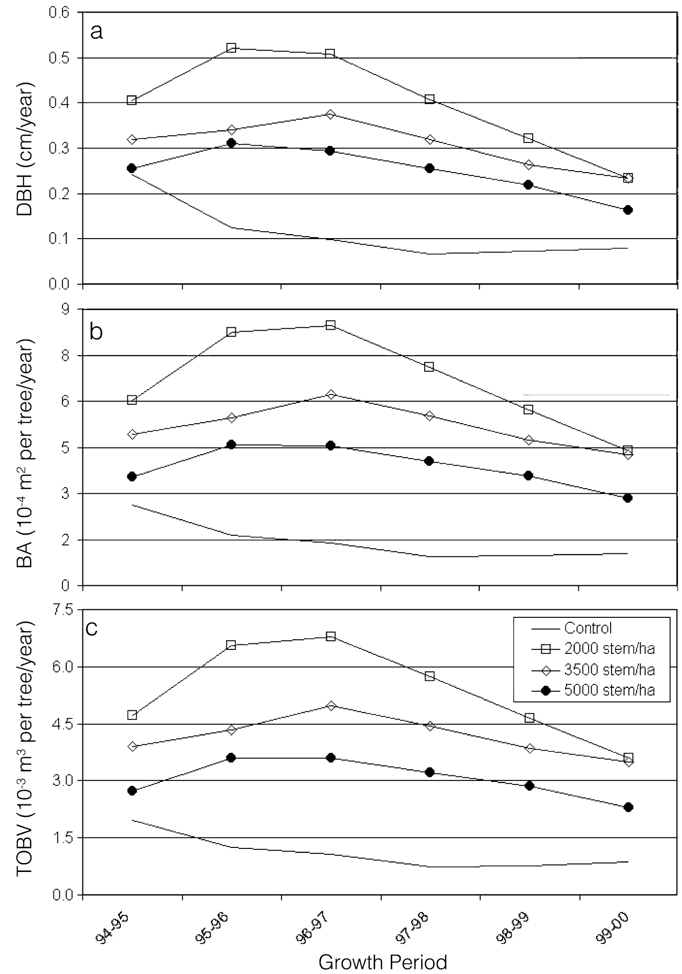

Figure 3. Individual tree diametric (a), basal area (b) and total over bark volume (c) growths of the control treatment and of the different thinning levels. DBH: Diameter at breast height; BA: Basal area; TOBV: Total over bark volume.

TABLE II
DASOMETRIC VALUES FOR THE UNTHINNED PLOT CONSIDERING MORTALITY AND INCREMENT

Annual	1996	1997	1998	1999	2000
Trees/ha	11700	11700	11500	10500	10300
DBH (cm)	7.2	7.3	7.5	7.7	7.9
BA (m²/ha)	56.6	58.0	59.2	58.2	59.3
TOBV (m³/ha)	403.7	414.5	424.2	419.5	429.0
Increment	1996-1997	1997-1998	1998-1999	1999-2000	
Trees/ha	0	-200	-1000	-200	
DBH (cm)	0.1	0.2	0.2	0.2	
BA (m²/ha)	1.4	1.2	-1.0	1.1	
TOBV (m³/ha)	10.8	9.7	-4.7	9.5	

DBH: Diameter at breast height. BA: Basal area. TOBV: Total over bark volume.

application, being the treatment of 5000 stems/ha significantly higher than the other two treatments, reaching a maximum average growth of 18.0m³/ha·yr. This same growth behavior was observed when the growth of the basal area of the thinned plots was analyzed (Table III and Figure 5a).

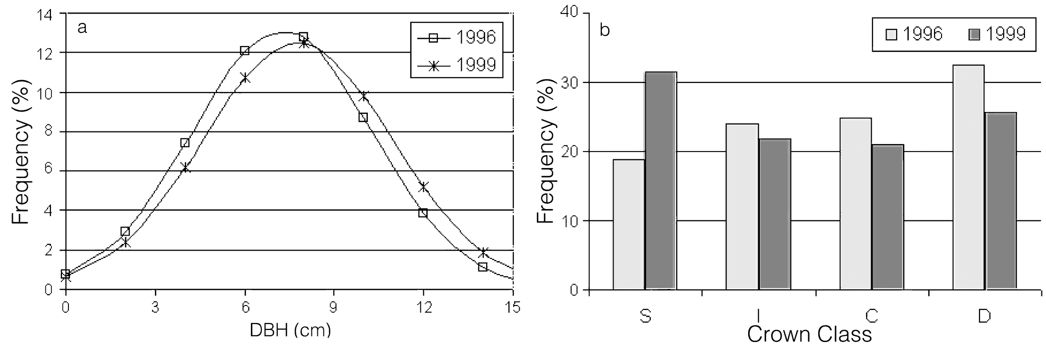

Figure 4. Diametric frequency distribution (a) and crown classes (b) for a period of four years in the control treatment. S: Suppressed; I: Intermediate; C: Co-dominant; D: Dominant; DBH: Diameter at breast height.

Discussion

Early silvicultural interventions in *Nothofagus betuloides* stands are useful tools to direct the growth toward the selected trees, since the natural self-thinning of the stand is avoided. A significant increase in growth could be observed, duplicating the volumetric increments at stand level. The obtained growth results in an attraction due to the decrease of the forest term, which could be achieved by managing intensively the regeneration areas. The trees possess an adequate natural pruning when they grow in compact natural masses. This situation does not occur in stands already thinned, and it is possible that pruning will be necessary in order to maintain the forest quality of the stems. Pruning of the remaining trees during the thinning treatments is an indispensable condition in young stands of *N. pumilio* (Martínez Pastur *et al.*, 2001). This is not necessary when the first thinning is carried out in stands with 80% of the maximum height of the site (Martínez Pastur *et al.*, 1997b, Peri *et al.*, 2000). Pruning is also cited as a necessary condition in *Castanea sativa* Mill. In England and France, where it is recommended to be carried out during thinning in order to obtain better wood quality and higher income (Everard and Christie, 1995). There are potential disadvantages in that heavily thinned trees tend to have more branches of larger size, as cited for *Betula pendula* Roth (Cameron *et al.*, 1995). The economical parameters that analyze pruning costs and benefits for the stand growth and the decrease of the forest term should be taken into account in order to define the thinning intensity level.

The values of total volume growth obtained are comparable with values obtained in other *Nothofagus* species, like in *N. obliqua* (Mirb.) Oerst., *N. nervosa* (Phil.) Dim. *et* Mil. and *N. dombeyi* (Mirb.) Oerst., which present better growth and productive potential, arriving to values up to 20m³/ha·yr at Valdivia, Chile (Donoso *et al.*, 1993), and up to 17m³/ha·yr in plantations of *N. obliqua* and *N. nervosa* in England (Tuley, 1980). Another species that presents excellent growth in Tierra del Fuego is *N. pumilio*. In stands at the initial growth phase, of site quality *II-III* according to the development phase classification proposed by Schmidt and Urzúa (1982), which follows Martínez Pastur *et al.* (1997b), the volumetric growths reach 12.7m³/ha (Martínez Pastur *et al.*, 2001). In thinned stands of final growth phase an increment of 10.3m³/ha·yr was obtained (Peri *et al.*, 2000) in a site of quality *I*, and of 8m³/ha·yr in Magallanes, Chile (Schmidt *et al.*, 1996) in a site of quality *IV*. On the other hand, if these results are compared with those in another *Fagaceae* species, they are closer

TABLE III
ANALYSIS OF VARIANCE FOR ANNUAL INCREMENTS OF THE THINNED TREATMENTS

DBH (cm/yr) Treatment	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000
2000 trees/ha	0.406	0.522b	0.508	0.407b	0.321	0.233
3500 trees/ha	0.302	0.340a	0.375	0.320ab	0.263	0.233
5000 trees/ha	0.255	0.311a	0.293	0.254a	0.220	0.163
F value	4.324	9.719	4.911	9.771	2.507	0.644
(significance)	(0.070)	(0.011)	(0.054)	(0.013)	(0.162)	(0.557)
BA (m²/ha·yr) Treatment	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**
2000 trees/ha	1.204	1.648a	1.691	1.421a	1.144	0.879
3500 trees/ha	1.725	1.909a	2.179	1.931b	1.658	1.497
5000 trees/ha	1.762	2.295b	2.266	2.023b	1.785	1.426
F value	5.127	19.087	1.973	11.680	3.241	1.091
(significance)	(0.050)	(0.002)	(0.219)	(0.008)	(0.111)	(0.395)
TOBV (m³/ha·yr) Treatment	**1994-1995**	**1995-1996**	**1996-1997**	**1997-1998**	**1998-1999**	**1999-2000**
2000 trees/ha	9.462a	13.100a	13.559	11.491a	9.280	7.199
3500 trees/ha	13.639b	15.188a	17.442	15.568b	13.465	12.204
5000 trees/ha	13.668b	18.026b	17.944	16.111b	14.245	11.521
F value	5.500	25.847	1.969	13.636	3.396	1.137
(significance)	(0.044)	(0.001)	(0.220)	(0.006)	(0.103)	(0.381)

DBH = diameter at breast height; BA = basal area; TOBV = total over bark volume. In each column means followed by different letters are significantly different at P<0.05 by Tukey's test.

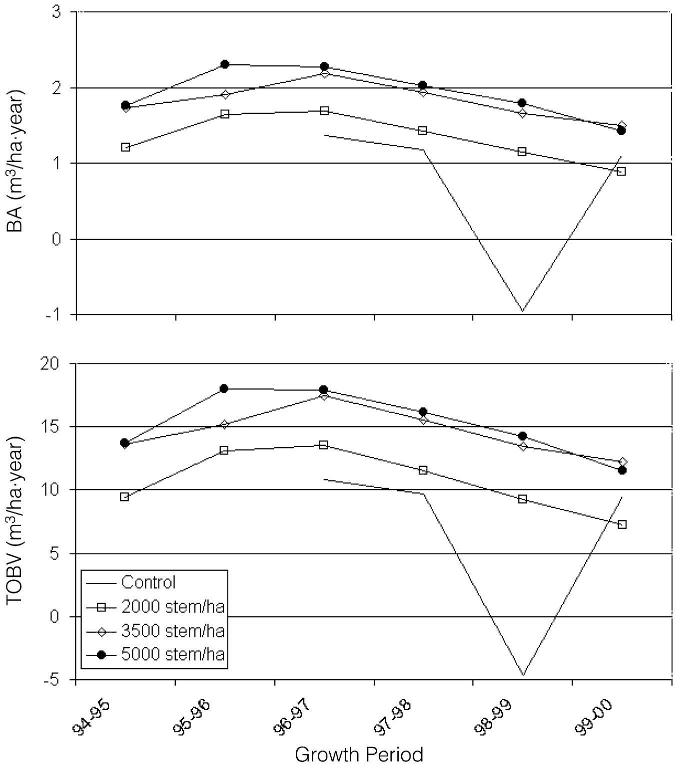

Figure 5. Stand basal area (a) and total over bark volume (b) growths of the control treatment and of the different thinning levels. BA: Basal area; TOBV: Total over bark volume.

to the ones presented for *N. betuloides*. For example, *C. sativa* reached a growth rate of 13.5m³/ha·yr in the south of England and of 16.0m³/ha·yr in northern France, the main reasons to promote the implantation of the species being their enhanced growth, simple silviculture and the wood quality (Everard and Christie, 1995).

N. betuloides is mostly present at the shores of the Beagle Channel and near the Escondido and Fagnano Lakes, Argentina, and large areas of this forest type were harvested between 1980 and 1995. These woods had a successful regeneration, and have adequate forest structures for their silvicultural management. This species has a high potential in order to be incorporated within a forest intensive management, but it is necessary to amplify the studies to other environmental conditions and to mixed stands where it grows with *N. pumilio*, as these two species live together in a forest area of 214000ha (Collado, 1999).

Besides, economical analyses will we carried out, due to the short period of the effective impact of the thinning.

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