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## Timber production of *Nothofagus pumilio* forests by a shelterwood system in Tierra del Fuego (Argentina)

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### Abstract

*Nothofagus pumilio* is the most important timber native species from south Patagonia of Argentina and Chile. The total volume and timber production vary according to site quality, stocking, growth phase and previous land management. The aim of this work was to evaluate the existence and the productive potential of wood for the sawmill industry in a shelterwood seed cut of *N. pumilio* forests along the range of site classes. Sample plots were established in 3 ha of an old-growth virgin forest without regeneration patches (SDI 95–131%) along the five classes of site (I–V). Total stand volumes varied from 400 to 1100 m<sup>3</sup>/ha and volume density index (ratio of total volume over basal area) varied from 6 to 14 m<sup>3</sup>/m<sup>2</sup>. The volume yield present differ significantly among site qualities with log volumes between 40 and 400 m<sup>3</sup>/ha. The number of timber logs decreases from the better sites towards the worst (800–200 logs/ha), as well as their volume average (0.5–0.2 m<sup>3</sup>/log). Several published studies in timber production were compared and discussed with the obtained results. Considering new alternatives in the *N. pumilio* timber management allow managers to obtain higher harvesting indexes, increasing the benefits for the forest company and diminishing the annual wood areas necessary to supply the requirements of the sawmills in Tierra del Fuego. © 2000 Elsevier Science B.V. All rights reserved.

**Keywords:** Shelterwood cut system; Volumetric yield; Forest structure; Site class; *Nothofagus pumilio*; Patagonia

### 1. Introduction

The *Nothofagus pumilio* forests (commonly named ‘Lenga’) are the main commercial woods in South Argentina and Chile (Garib, 1996). It is a medium shade intolerant species (Rusch, 1992) that has patchy cycles of regeneration due to the natural mortality of trees (Rebertus and Veblen, 1993) which introduces an irregular heterogeneous structure that hinders plan-

ning of forest management. The shelterwood system best simulates the natural dynamic by opening the canopy to allow regeneration. This practice transforms the virgin forest into a regular managed one, resulting in higher size increments, better stand health and quality of wood, in improving the harvesting index and the subsequent sawmill efficiency (Schmidt and Urzúa, 1982). The shelterwood system is silviculturally appropriate to manage these woods, resulting in an abundant natural regeneration successfully installed. This is possible, because Lenga forests are mainly grow in pure stands.

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There are 220,000 ha of timberland in Tierra del Fuego (Argentina). Stand values of volume vary between 300 and 1300 m<sup>3</sup>/ha according to site quality, stocking, growth phase and previous land management (Martínez Pastur et al., 1994). There is a site quality categorization for these forests (I–V) (Martínez Pastur et al., 1997) based on the potential productivity in South Patagonia. The majority of these commercial forests belong to site quality III and show a dominant height of 20.5–24.0 m at a maturing growth phase ( $SI_{60}=13.1-16.5$  m). The classification of Lenga growth phases was defined by Schmidt and Urzúa (1982) in optimum, maturing and senescence, according to the stand age.

The resource supply of wood has decreased in the last years, prevailing a non desirable silvicultural system based on the selective cut of the better timber trees. This system was locally named as *floreo* and is incompatible with a sustainable forest management (Mosqueda, 1995). By the way, the *floreo* degrade the forest quality, impoverish the potential timber productivity in the future stand. This practice harvest a 20% of the timber potential of the stand, and this incomplete cut not reach the correct regeneration of the stand (fragment the regeneration on isolated patches).

Therefore, authorities of the provincial Forest Service promote the optimization of the forest management through the improvement of the yield harvesting applying a complete shelterwood cut system. Timber production in Tierra del Fuego is absorbed mainly (70%) by the internal market for building material that needs large piece sizes (planks, boards and struts), necessitating a high log selection in the forest (4–6 m long, diameters over 35 cm and sound). The remainder of the production (short size sawn wood) goes to local furniture industry, or to industry of strips, boards, finger-joint and parquets. Another outlet that absorbs the minor quality wood is the chip production (Mosqueda, 1995), but that is not carried out since the Tierra del Fuego law number 202 restrict the export of unprocessed wood.

The traditional harvest system consists in the tree-falling, the butt log cut called “desculate” and the production of long logs in the forest. A low percentage of harvesting indexes of 5–10% (log volume over total stand volume) with volumes of 40–60 m<sup>3</sup>/ha are obtained through the application of this system. A non-traditional harvest system based on the whole

stem extraction and the obtaining of the logs in the piling zone allows to increase the harvesting index in a significant way (Cellini et al., 1998). On the other hand, this system decreases the harvesting costs and optimizes the work of the faller, the efficiency of the skidder and diminishes the loss of logs in the forest.

The aim of this work was to evaluate the existence and the productive potential in quantity and quality of wood for the sawmill industry in a shelterwood seed cut of *N. pumilio* commercial forests of Tierra del Fuego (Argentina) along the range of site classes. In these, work are taken on that the maximal harvesting efficiency is achieved by the application of a complete shelterwood cut and logging through the non-traditional system described before.

## 2. Materials and methods

### 2.1. Study area

An old-growth *N. pumilio* pure forest was selected in San Justo ranch — Tierra del Fuego (54°06'SL, 68°37'WL) (Fig. 1) along the site class range defined by Martínez Pastur et al. (1997), where ‘Los Castores’ sawmill carries out harvesting. The regeneration method uses the shelterwood cut system (Schmidt and Urzúa, 1982) according to the regulation of Tierra del Fuego forest law number 145. The forest land use is exclusively for timber production, without cattle grazing, but with a significant pressure of *Lama guanicoe* (‘guanaco’) browsing on the saplings (Skrk et al., 1997). The trial was done in 3 ha, where plots of 40 m × 50 m were installed along the five classes of site (I–V) (three plots per site class). The original structure of the forest was characterized by the average and dominant height (100 taller trees/ha), basal area, quadratic mean diameter (QMD), number of trees/ha and total over bark volume/ha.

### 2.2. Marking of the leave trees, tree-falling and volume measure

When the leave trees of the overstory were marked, 30 m<sup>2</sup>/ha of basal area was left with a maximum distance between trees of 12 m and uniformly distributed over the unit. The selected trees were dominant or codominant, with long, full, symmetrical

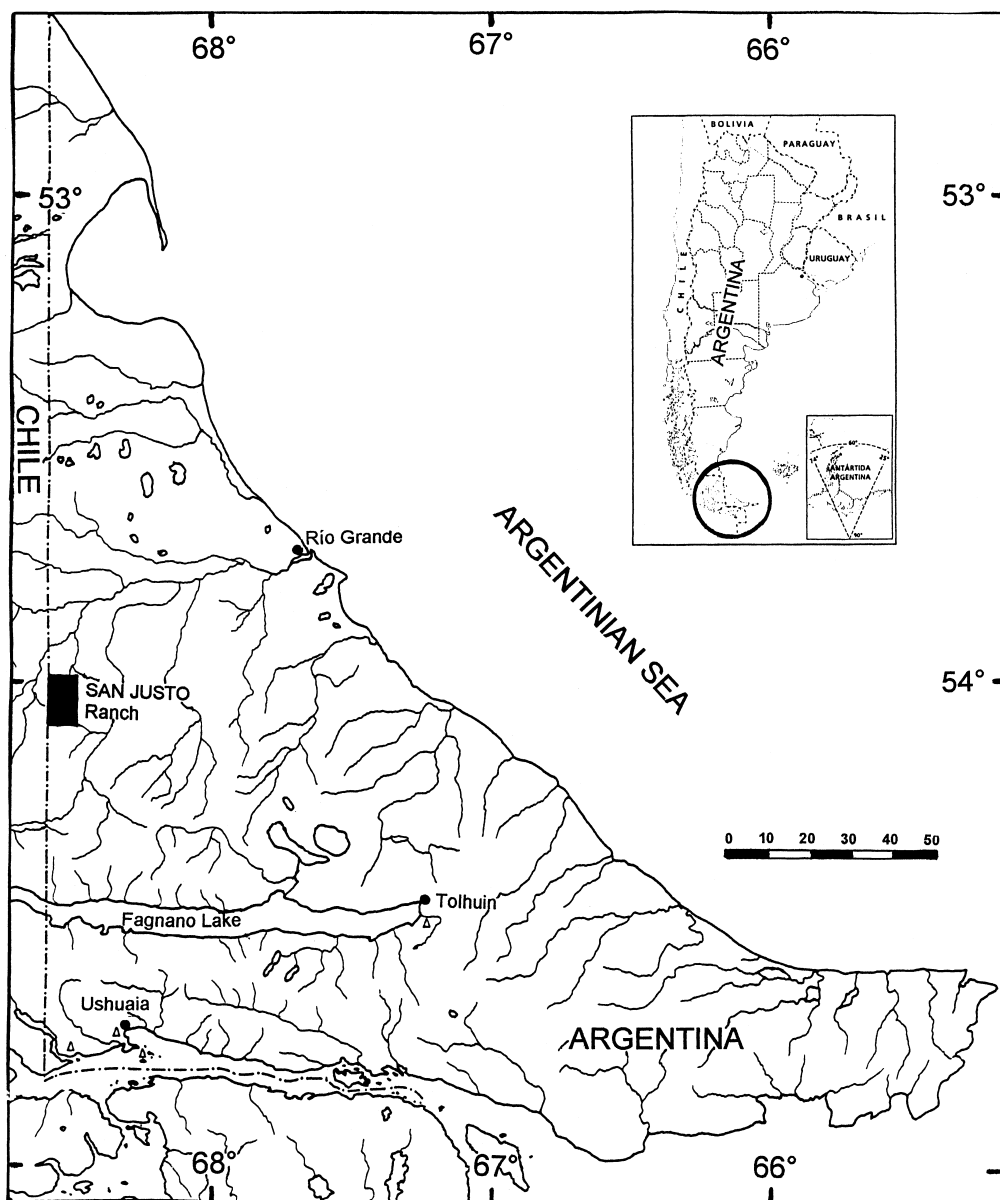


Fig. 1. Location of the study area.

crowns. They were judged to be the better seed producers, the most wind firm (low ratio of total height over QMD) and with a minimum sawtimber volume. The falling of the trees was carried out with qualified personnel with chainsaw. The timber stems (a cut in the base bole and another in the diameter restriction of 20 cm) were extracted with skidders to the piling zone,

where the timber logs for the sawmill were obtained (3–5 m long). The same were classified according to quality categorization by Cordone and Bava (1997) (quality A — long logs without defects; quality B — long logs with minor defects; quality C — logs with located defects or bad form; quality D — logs with generalized defects and bad form). The volumes of the

trees, stems and logs were measured along all the trial. The Smalian formula was utilized for the log volume estimation, while the Newton formula was used for the stems (Ferrando, 1994; Garib, 1996). Total volume of the leave trees was estimated using standard equations proposed by Peri et al. (1997).

### 2.3. Statistical analysis

An analysis of variance was carried out to analyze the yield and forest structure along the site quality range, by *F*-test. The separation of the means was done by Tukey test. The level of significance was  $P < 0.05$ .

## 3. Results and discussion

### 3.1. Characterization of the original forest structure

The forests sampled along the site quality range possess the structure of an old-growth irregular forest with one or two stratum, without regeneration patches (Table 1). The average density of the stands varied between 95% and 131% for the sites I–V according to the Reineke's index proposed by Fernández et al. (1997). These values indicate that the stands are stocked or overstocked (61–82 m<sup>2</sup>/ha of basal area). Along the studied site quality range, the individual trees of the stands are mainly in maturing growth phase (120–250 years old) (35% at 73% of the trees) and/or in senescence growth phase (ages up to 250 years) (12% at 35% of the individuals) (for further information about growth phases characterization, see Schmidt and Urzúa, 1982). An important percentage of individuals in this last growth phase (40%) were left as leave trees after the shelterwood

seed cut. This type of structure is the most representative of the old-growth productive forests of Tierra del Fuego, with over mature stands, overstocked and with a high percentage of timber trees.

When comparing the original structure of the stands between the site classes by an analysis of variance: significant differences in number of trees, QMD, average height of the stand, dominant height of the stand and total volume were detected (Table 1). The basal area did not present significant differences between sites, representing the maximum values for the occupation grade of the species. This was cited in other studies of *N. pumilio* forest structure (Martínez Pastur et al., 1994). However, the basal area differences between sites should be kept in mind when the yield volume was analyzing, since it influences directly the stand volume. In the remainder studied variables, gradient values were detected. Some of them were positive (number of trees) and some of them negative (QMD, average and dominant height, total volume) from the better sites (site I) towards the worst sites (site V). These gradients are cited in the *Nothofagus* bibliography for different environmental conditions that influence directly the site quality (Dimitri, 1964; Donoso, 1987; Hasse, 1990; Fernández et al., 1993; Martínez Pastur et al., 1994; Lusk, 1996).

### 3.2. Variation of the forest structure during the harvesting

When the tree falling is carried out, 54–64% of the original basal area is taken out, cutting trees between 20 and 100 cm QMD, with an average range from 23 cm in a site V to 42 cm in a site I. On sites I–V, 256–800 trees/ha were cut, representing the removing of

Table 1  
Analysis of variance of the forest structure along the site quality classes<sup>a</sup>

Site class	<i>N</i> (trees/ha)	QMD (cm)	BA (m <sup>2</sup> /ha)	AH (m)	DH (m)	TOBV (m <sup>3</sup> /ha)
1	382.5a	46.8c	76.6a	23.5c	27.5e	1098.7c
2	332.0a	44.9c	61.0a	22.1c	25.4d	815.0bc
3	746.6b	32.9ab	81.5a	17.1b	21.5c	897.9bc
4	433.3a	40.2bc	60.8a	14.9b	17.4b	536.4ab
5	1026.6c	25.6a	65.9a	10.4a	13.7a	397.6a

<sup>a</sup> *N* is the number of trees, QMD the quadratic mean diameter, BA the basal area, AH the average height of trees, DH the dominant height of trees, and TOBV the total over bark volume of trees. Values of *F*-test = *N*(29.8); QMD(22.0); BA(2.5); AH(112.9); DH(378.4); TOBV(9.8). Different letters means significant differences at  $P < 0.05$ .

78–82% of the individuals. In good sites (I and II) the 80% of the logged trees were in maturing growth phase, while in lower sites the percentage diminished gradually until 32%, increasing significantly the number of trees in senescence growth phase. The individuals in maturing growth phase are the trees that contribute with the higher percentage of healthful timber yielding logs (Donoso and Caldenty, 1995), being in their great majority codominant (good stem form with wide crowns and without external damages). The average results obtained in the evaluation of the shelterwood system show similar percentages to those produced by Cellini et al. (1998).

The remaining canopy consisted of a cover of seed trees, uniformly distributed with 30 m<sup>2</sup>/ha of basal area. In the logging of the Fuegian forests it is suggested to leave 40% of the original basal area, but this implicate a great variation in the remnant protection overstory, since it is related to the original structure. There are poorly-stocked forests (40 m<sup>2</sup>/ha of basal area) that would remain too open (16 m<sup>2</sup>/ha) if 60% of the original basal area is cut, while the overstocked forests (90 m<sup>2</sup>/ha of basal area) would remain too closed (36 m<sup>2</sup> of basal area/ha). This fact took us to define an optimum basal area for the canopy protection (20–25 m<sup>2</sup> of basal area) plus 25% due to the high fallen of trees in the first posterior years to the logging of the forest. The remaining canopy was conformed by trees of good form, whose QMD varied gradually from 37 cm in the site V until 66 cm in the site I, being 20% of the original trees of the stand. Average inter tree distance varied between 7 and 12 m (225–70 trees/ha), for the sites V and I. The whole leave trees were in senescence or maturing growth phases, mainly of dominant class (80% of the individuals).

### 3.3. Volume characterization along different site qualities

Total volumes showed a gradient along the sites and varied between 400 and 1100 m<sup>3</sup>/ha (Table 1), for the studied density levels (60–80 m<sup>2</sup>/ha of basal area). The volume density index (VDI) (ratio of total volume over basal area) varied significantly between sites (Fig. 2A), from 6 m<sup>3</sup>/m<sup>2</sup> (site V) to more than 14 m<sup>3</sup>/m<sup>2</sup> (site I). These differences justify the use of this basic parameter in the biometrics characterization done in a forest inventory. This ratio gives

independent of stand degree stocking information, and that is the reason why it will be the comparative parameter to use.

The harvested volume presents significant differences between site qualities (Table 2) when the logs were obtained according to the logging system proposed by Cellini et al. (1998). Yield indexes (ratio of log volume over total fell volume) show a range along the sites, from 30% (site V) to 75% (site I). The stem volume density index (SVDI) (ratio of stem volume over logged basal area) varied from 2 m<sup>3</sup>/m<sup>2</sup> for a site V to 11 m<sup>3</sup>/m<sup>2</sup> on a site I. These indexes are directly related to the efficiency in falling and skidding tasks. For each square meter of basal area that the fallers cut in a site I, they will get five times the product than in a site V. Anyway, logs will be bigger in the best sites, diminishing the costs/m<sup>3</sup> of skidding with wire ropes.

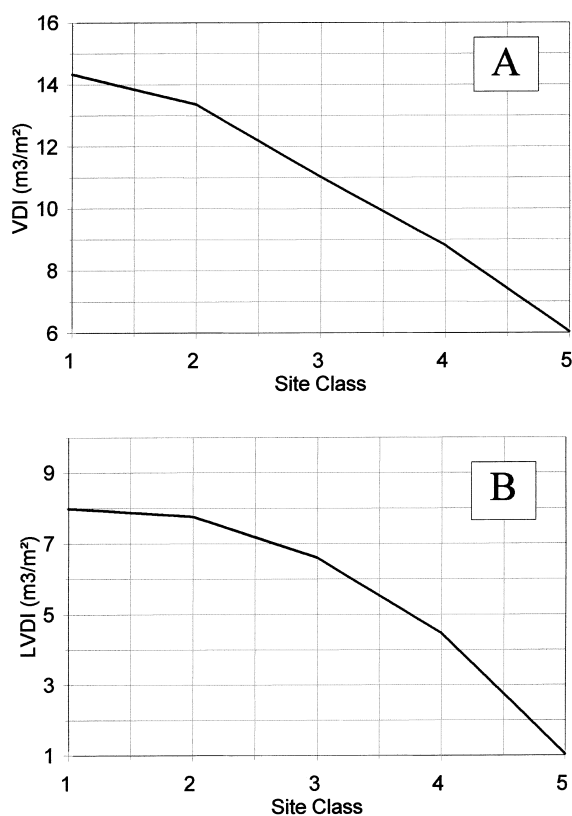


Fig. 2. VDI (RATIO OF TOTAL VOLUME OVER BASAL AREA) (A) and LVDI (RATIO OF LOG VOLUME OVER LOGGED BASAL AREA) (B) along the site quality range.

Table 2  
Analysis of variance of quantity and quality of timber volume along the site quality classes<sup>a</sup>

Site class	SOBV (m <sup>3</sup> /ha)	LUBV (m <sup>3</sup> /ha)	LQA (m <sup>3</sup> /ha)	LQB (m <sup>3</sup> /ha)	LQC (m <sup>3</sup> /ha)	LQD (m <sup>3</sup> /ha)
1	530.0c	398.8c	89.5b	154.8c	135.2a	19.1a
2	338.2bc	263.1bc	50.4ab	121.6bc	76.8a	14.3a
3	330.7abc	237.7abc	28.7a	77.9abc	89.9a	41.2a
4	215.5ab	145.9ab	11.1a	27.2ab	79.9a	27.7a
5	73.3a	42.0a	0.6a	6.0a	24.5a	10.9a

<sup>a</sup> SOBV is the stem over bark volume of cut trees, LUBV the log under bark volume obtained from the stems, LQA the volume of logs of quality A, LQB the volume of logs of quality B, LQC the volume of logs of quality C, and LQD the volume of logs of quality D. Values of *F*-test = SOBV(9.0); LUBV(10.1); LQA(8.8); LQB(6.3); LQC(2.8); LQD(2.1). Different letters means significant differences at *P* < 0.05.

The timber volume obtained after the conversion of stems to logs represent 55% in a site V to 76% in a site I. These volumes (log under bark volume) varied significantly between sites, from 40 to 400 m<sup>3</sup>/ha (Table 2). The log volume density index (LVDI) (ratio of log volume over logged basal area) varied between sites (Fig. 2B), from 1 m<sup>3</sup>/m<sup>2</sup> (site V) to 8 m<sup>3</sup>/m<sup>2</sup> (site I).

The number of produced logs diminishes from the better sites towards the worst (near 800 in a site I to 200 in a site V), as well as their volume average (0.5 m<sup>3</sup>/log in a site I to 0.2 m<sup>3</sup>/log in a site V). The proportion of small logs (less than 30 cm of diameter) are not significant in a site I (31%) but it increases upon diminishing the site quality, arriving at 79% in a site V. The obtaining of big logs (bigger than 40 cm of diameter) has their maximum in a site I (29%) and subsequently diminish until 5% in a site V. The whole realization of the shelterwood cut contributes an important volume of small diameter logs. This volume represents a high percentage of healthful wood that usually remains in the forest next to the crown or standing, being despised because of its low individual log volume. In many sawmills of Tierra del Fuego, the payment to the fallers is carried out for number of logs obtained (rarely is per volume), what leads the owners to demand big logs of good quality and sound.

The volume of logs discriminated by qualities is largely influenced by the site (Table 2 and Fig. 3). The percentage of A quality volume decreases from 22% in a site I to 1% in a site V. The great percentage of logs is in B and C qualities, representing the D quality volumes 5–25% of the produced logs. Traditional sawmills aim to obtain big logs of A or B qualities by a selective cut system (*floreo*) and

consequently, the realization of this practice is not economically possible in forests of quality IV or V. The adaptation of the forest industry to the products obtained in the shelterwood cut will permit a more efficient utilization of the resource, increasing the harvesting index and diminishing the costs of logging and production. The compartmentalization expressed as total volume percentage (remnant, log and residue volumes) along the gradient of site classes is showed in the Fig. 4. The application of the shelterwood system implicates the use of 60% of the total volume of the old-growth forest, leaving the other 40% as the canopy of protection. The volume of residue that remains thrown in the forest or in the piling zones (mainly compound for stumps, putrid wood, branches or bark) represents between 20% and 80% of the cut volume (from sites I to V). The volume that arrives to the sawmill represents between 34% (site I) and 11% (site V) of the total volume of the forest (or between 60% and 20% of the logged volume).

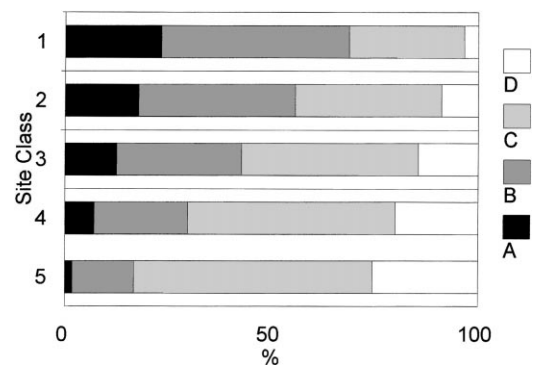


Fig. 3. Percentage of quality logs (A–D) processed in the piling zone along the site quality range.

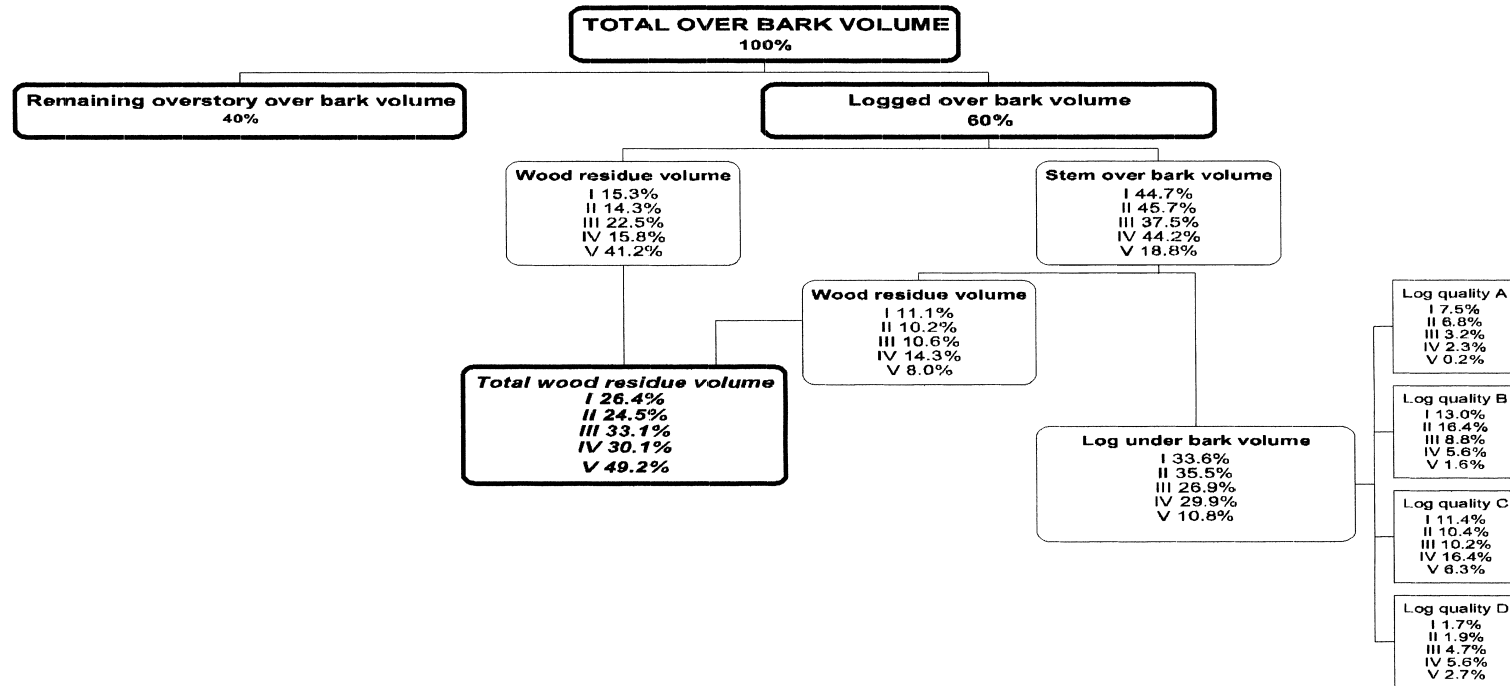


Fig. 4. Compartmentalization expressed as total volume percentage (remnant, log and residue volumes) along the gradient of site classes in an *N. pumilio* shelterwood cut system in Tierra del Fuego.

Table 3  
Timber volume obtained along *N. pumilio* forest (Chile and Argentina) in a shelterwood cutting<sup>a</sup>

Place	Site class	TOBV (m <sup>3</sup> /ha)	TOBV/BA (m <sup>3</sup> /m <sup>2</sup> )	LUBV (m <sup>3</sup> /ha)	LUBV/CBA (m <sup>3</sup> /m <sup>2</sup> )
San Justo <sup>b</sup>	3	850.3	11.6	255.9	6.0
Russfin <sup>c</sup>	2	945.3	12.5	190.3	3.8
Monte Alto <sup>d</sup>	4	776.2	9.3	166.7	3.5
Aysén <sup>e</sup>	3	547.6	11.5	72.5	2.6
Tolhuin <sup>f</sup>	3	586.9	10.0	179.7	5.9
M <sup>b</sup> Cristina <sup>f</sup>	3	535.1	10.5	152.1	4.1
Preto Oeste <sup>f</sup>	3	750.2	10.4	266.5	5.7
Tolhuin <sup>g</sup>	3	659.0	10.7	33.0	–

<sup>a</sup> TOBV is the total over bark volume, TOBV/BA the ratio between TOBV and the basal area, LUBV the log under bark volume, and LUBV/CBA the ratio between LUBV and the cut basal area.

<sup>b</sup> Tierra del Fuego (Argentina) in Cellini et al. (1998).

<sup>c</sup> Tierra del Fuego (Chile) in Garib (1996).

<sup>d</sup> XII región (Chile) in González (1995).

<sup>e</sup> XI región (Chile) in Ferrando (1994).

<sup>f</sup> Tierra del Fuego (Argentina) in Daffunchio and Villena (1997).

<sup>g</sup> Tierra del Fuego (Argentina) in Bava and Hlopec (1995).

### 3.4. Comparison of volumetric yield between site classes

The forests studied in the literature belong to site classes II–IV, varying the total over bark volumes between 535 and 945 m<sup>3</sup>/ha and the VDI (ratio of total volume over basal area) between 9 and 13 m<sup>3</sup>/m<sup>2</sup>. The forest structure of these stands is comparable to those described for similar site qualities (Tables 1 and 3). The volumes obtained in the shelterwood cut system vary according to several authors, between 33 and 266 m<sup>3</sup>/ha. These differences are mainly due to the harvesting techniques that were used, as well as for the forest management objectives or the characteristics of the studied stand. The assays of González (1995), Garib (1996) and Cellini et al. (1998) gave priority to the extraction of timber yielding volumes, but maintaining the possibility of log production for chips using the minor quality wood. Bava and Hlopec (1995) aimed the obtaining of high quality logs through a traditional harvesting method for the saw-mill industry in Tierra del Fuego. On the other hand, Ferrando (1994) worked in a mixed forest of Lenga-Coihue for which it gave less stand yield than the other situations. From all the assays, the values got by González (1995), Garib (1996), Daffunchio and Villena (1997) and Cellini et al. (1998) are similar to those obtained in this work for the plots of the same site quality. The harvesting index (ratio of log volume

over total volume) achieved along the site quality range varied in a gradient from 11% (site V) until 36% (site I), while the authors obtained values between 20% and 35%. It implicates that they have carried out a complete shelterwood cut. Finally, the LVDI (ratio of log volume over basal area) varies between 3 and 6 m<sup>3</sup>/m<sup>2</sup>, setting within the ranges detected in our research (Fig. 2A).

### 3.5. Final considerations

When a shelterwood cut is carried out, a high stand volumetric yield was obtained and the virgin forest is transformed in a regular system with all the advantages that implicates it (Schmidt and Urzúa, 1982). However, it is necessary to conduct additional research in the level of canopy protection to leave (as a fixed density level and not as a percentage of the original basal area) according to the site quality and stand conditions (wind exposition, soil humidity, slope, etc.), that could influence the post-harvesting dynamics.

The wood yields obtained in this work are comparable to studies carried out in Argentina (Daffunchio and Villena, 1997; Cellini et al., 1998) and Chile (González, 1995; Garib, 1996), being possible of applying economically to a great scale in all commercial forest of Tierra del Fuego. To achieve the aims of the theoretical model of a shelterwood system, it is



necessary take in account: (a) the integral harvesting of the forest products, (b) the adaptation of the sawmill industry to the wood resource, (c) the sawn products diversification and (d) the increasing of the commercial products added value. However, when a complete shelterwood cut is done, a high percentage of small diameter logs are produced and it is necessary to find a market for this product. In Tierra del Fuego (Argentina) the great scale chip generation is not possible, because the exportation of this product is forbidden and there is no any local chip consumer industry. The practicability of this process (without chips production) that maximize the harvesting volumes in all the site quality range is demonstrated through the activities that 'Los Castores' sawmill is carrying out. This company processes 20,000–25,000 m<sup>3</sup> log/year (100–160 ha/year), producing 4 million board feet/year (9000–10,000 m<sup>3</sup> of saw timber/year) (40% in planks, boards and struts for the local market; 60% for the production of strips and strip-boards for the exportation market). In the sawmill, the 1997–1998 yield was 41% (ratio of sawn wood over log volume).

The stand classification according to their site quality during the forest inventory is very important for the correct planning of the forest harvesting (Mac Lean, 1980). The site index is highly correlated in quantity and quality with the stand volumes (total and timber yielding). Site class and the stand stocking will define the levels of extraction and will determine the harvesting economical limits for a certain industry (according to the size and quality of logs that should process). Considering new alternatives in the Lenga timber management allow to get higher harvesting indexes, increasing the benefits for the forest company and diminishing the annual wood areas necessary to supply the requirements of the sawmills in Tierra del Fuego.

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