

1 **Modelling dominant height and site index in different edaphoclimatic zones of *Nothofagus***
2 ***dombeyi* secondary forest in the Andes of south-central Chile**

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10
11 **Abstract**

12
13 *Nothofagus dombeyi* grows in a wide variety of sites. The information about its
14 productivity is still scarce, which makes it difficult for foresters and owners of the land to take
15 decisions about the best practices to maintain and/or improve the goods and services derived
16 from the forest. The aim of this study was to construct dominant tree height functions and site
17 index curves for secondary forests *Nothofagus dombeyi* (coihue) in south-central Chile. We
18 measured 100 sample units throughout three edaphoclimatic zone, and 300 dominant trees (three
19 per plot) were used for stem analysis Three nonlinear growth models (Chapman-Richards,
20 Weibull and Logistic) were fitted, and the best model for each edaphoclimatic zone corresponded
21 to Chapman-Richards. In addition, it was determined that for each zone it was necessary to obtain
22 a given growth model given the high variability of sites. The best tree height growth
23 corresponded to zone 2, followed by zone 1 and zone 3. In zone 2 trees reach 31 meters at age 60,
24 in zone 1 29 meters, and in zone 3 shows 24 meters, indicating variations in growth patterns and
25 differences between zones. We recommend using the models for a range of age between 10 and

26 60 years (base age 35 years). This study is the first to describe a large scale growth of *N. dombeyi*
27 for the southern cone of American in secondary forests where they appear as one of the most
28 important forest resources and less management in the zone.

29

30 **Keywords:** evergreen, coigüe, forest station, dominant height, polymorphic.

31

32 **Introduction**

33

34 Height growth is a reflection of site quality because height is usually independent of
35 density (Carmean 1975, Clutter et al. 1983, Fontes et al. 2003). Determination of forest
36 productivity according to site quality for commercially interesting species is relevant for
37 landowners to know the potential growth of their forests, but also for governments to assign
38 subsidies according to this productivity, or to local authorities to plan land use at a local or
39 regional scale (Kitikidou et al. 2012). The knowledge of the differential productive potential by
40 site for a given forest type or subtype is also essential to define silvicultural systems conducive to
41 orienting the provision of desired goods or services from a given forests, allowing for a
42 sustainable use of the resources (Esse et al. 2013).

43 The *Nothofagus* species forests of the southern cone of South America represent dominant
44 forest ecosystems in the region (Veblen et al. 1996). In Chile these *Nothofagus* forests represent
45 the greatest productive potential from native forests to build up a formal economy based on
46 timber from these forests. It is estimated that of the 13,4 m ha of native forests in Chile there are
47 3,8 ha dominated by secondary *Nothofagus* forests (CONAF et al. 2011). These secondary forests
48 are mainly the result of past exploitation of primary forests, human-induced fires, or
49 abandonment of lands previously used in agriculture (Lara 1996, Camus 2006). These forests are

50 economically attractive due to their fast growth (Donoso et al. 1999, Salas and García 2006, Esse
51 et al. 2007), high densities (Gezán et al. 2007) straight boles of their trees, and quality of the
52 timber of the *Nothofagus* species (Díaz Vaz et al. 2002).

53 One *Nothofagus* species of great interest in Chile and Argentina is *N. dombeyi* (Mirb.)
54 Oerst. since it is the *Nothofagus* best adapted to grow in a great diversity of sites. In Chile, it
55 grows from the central (30°S) to southern (47°S) Chile and throughout the Coastal and Andean
56 ranges (Donoso et al. 2006, Esse et al. 2007, Esse et al. 2013). Secondary forests of this species
57 have been reported to grow more than 20 m³ ha⁻¹yr⁻¹ after age 25 years (Donoso et al. 1999), and
58 on average 40% more in basal area than secondary forests dominated by *N. alpina* or *N. obliqua*,
59 other related species of great economical potential (Lusk and Ortega 2003). Although the high
60 growth rates of *N. dombeyi* seem to occur throughout its distribution, it is necessary to develop
61 more specific measures of their productivity in order to take better informed decisions regarding
62 its management or other alternative uses.

63 Site quality can be estimated from the site index (Clutter et al. 1983, Payandeh and Wang
64 1994) which is defined as the dominant height at a base age (García 1983). According to Carrero
65 et al. (2008), the dominant height is a good indicator of the potential productivity of a species for
66 a particular site, a claim that is based on the hypothesis of Eichhorn (Fontes et al. 2003, Carrero
67 et al. 2008) who states that the total production of a stand is occupied optimally depending on the
68 height of the stand. The site index has been developed primarily for the study of single-species
69 even-aged plantations (Clutter et al. 1983, Ivancich et al. 2011), which is similar to second-
70 growth forests of *Nothofagus* that derive mostly from one single cohort and are dominated by
71 species of this genus (Ramírez and Figueroa 1987, Ivancich et al. 2011). For this reason some
72 studies of site index curves have already been developed for other *Nothofagus* species (Martínez
73 Pastur et al. 1997, Trincado et al. 2002, Esse et al. 2007, Ivancich et al. 2011).

74 In Chile, there are few studies that have defined growing zones for native forest species.
75 De Camino (1976) conducted a definition of forest management units, using the homogenous
76 stand concept. Likewise, Donoso et al. (1993) proposed growing zones for secondary forests of
77 *N. obliqua* and *N. nervosa* in their natural distribution range, based on biophysical and
78 productivity attributes. Echeverría and Lara (2004) defined growing patterns in secondary forests
79 of *N. obliqua* and *N. nervosa* in Cautín and Valdivia provinces based on edaphoclimatic
80 variables. Recently, Esse et al. (2013) described five different growing zones for *N. dombeyi*
81 through the integration of biophysical factors (Climate, soil and topography). This author looked
82 for identifying those key factors and variables that are mainly associated to growth and
83 development of this specie. However, these results demonstrated that it is absolutely essential to
84 increase the quality and precision of database relative to the natural distribution of species, as
85 well as being able to spatialize this information.

86 This study had the main objective of developing a dominant tree height growth model as a
87 function of age in secondary *N. dombeyi* forests in three edaphoclimatic zones in the Andes of
88 south-central Chile. With this, the hypothesis tested on the need for a dominant height model
89 growth in all three edaphoclimatic zones, which sought to validate the proposed zoning by Esse
90 et al. (2013). For this purpose we analyzed the variability in dominant height growth for each
91 edaphoclimatic zone for *N. dombeyi* secondary forests as defined by Esse et al. (2013). Therefore,
92 our objectives are to a) fit models for each zone and validate them with independent samples, and
93 b) compare these models with the aim of identifying if there can be a single dominant height
94 model for the region.

95

96 **Materials and methods**

97

98 ***Study area***

99
100 The study was conducted in an area of the Andes Mountains of south-central Chile (38 °
101 50 S, 40 ° 50 S) which covers a total of 1.2 million ha and includes 132,750 ha of secondary
102 forests of *N. dombeyi*.

103 The climate is temperate and rainy but with a short summer dry season due to
104 mediterranean influence in the region (DGF-Conama 2006, CEPAL 2012). According to Esse et
105 al. (2013), the area is divided into three edaphoclimatic homogeneous zones where *N. dombeyi*
106 secondary forests grow (Figure 1). Zone 1 is characterized by the dominance of low temperatures
107 (<10 ° C), high rainfall (>3,500 mm) and altitudes ranging between 700 and 1,300 m. Zone 2 is
108 characterized by having a lower mean annual precipitation (2,250 mm) and is located at low
109 altitude sites. Zone 3 has rainfall and temperatures similar to zone 2 but with very deep soils
110 (>100cm).

111

112 ***Data collection and analysis***

113

114 In each homogeneous edaphoclimatic zone, *N. dombeyi* secondary forest stands without
115 apparent recent past human intervention were selected (stands with densities up to 4,000 trees per
116 hectare and a high presence of dead and suppressed trees), establishing a total of 100 sample units
117 500 m² (20 x 25 m) in size each, which were randomized into three homogeneous zones. In each
118 sampling unit we selected and felled three dominant trees for stem analysis (123 in zone 1, 57 in
119 zone 2, and 120 in zone 3) resulting in a total of 300 trees. For each tree we obtained ten stem
120 cross sections, which were removed at 0.3, 0.8, 1.3 and meters, plus six cross sections between

121 1.3 m and the base of the tree crown (which was divided into six equal parts). For each tree we
122 also measured total height.

123

124 **Figure 1.**

125

126 Since the length of the sections is not necessarily the end of the annual vegetative growth,
127 we applied the bias correction method for determining height growth proposed by Carmean
128 (1972) and modified by Newberry (1991) with the support from the WinStemand Windendro
129 softwares (Regent Instruments Inc. 2005). A total of 3,000 age-height records were obtained.
130 Once the database was built, we removed outliers with the 'outliers' routine from the R statistical
131 software (Komsta 2011). Finally, the data were divided into two groups, the first corresponding
132 to 80% of information with which models were adjusted and evaluated, and the remaining 20%
133 that was used for validation. Finally we used 240 trees for the analyses (Table 1).

134

135 **Table 1**

136

137 *Model fitting*

138

139 We selected three nonlinear models, each with three parameters (Table 2), for fitting
140 dominant height functions in each edaphoclimatic zone. These models were chosen as candidate
141 functions since they are the most used in forestry research (Cieszewski and Bella 1989, Palahí et
142 al. 2004, Upadhyay et al. 2005, Carrero et al. 2008). In each model, the parameter 'a' represents
143 the asymptote or maximum value that can be reached, parameter 'b' corresponds to a global
144 parameter for all stands related to the height reached to the base age, and 'c' is a stand-specific

145 local parameter and could represent some particular condition of the site (García 2005, Carrero et
146 al. 2008). To fit each of the models, we chose the algebraic difference method (ADA), where the
147 choice of the parameter to eliminate determines the behavior of the model. If the asymptote
148 parameter is replaced, anamorphic curves occur, and the replacement of any other parameter will
149 produce polymorphic curves with equal or different asymptotes. Based on the above, it was
150 decided to replace the parameter 'b' in the selected model, achieving polymorphic curves, which
151 pass through the point where the height is equal to the site index, according to the base age
152 selected(Clutter et al. 1983, Alvarez et al. 2004,Kitikidou et al. 2012). The fit of the models was
153 performed by nonlinear least squares, for which we used the R and 'NLS2'statistical software
154 packages and, including the algorithm 'brute-force' that allows a good estimate of the starting
155 values of the model (Grothendieck 2013).

156

157 **Table 2**

158

159 *Base age selection*

160

161 For the base age selection we used different base age data and their corresponding
162 observed heights which were utilized to calculate the relative error (RE %) according to formula
163 [1]. This equation allows comparison of the observed values in the stem analysis with those of the
164 estimated values of the site function (Alvarez et al. 2004).

165

$$166 \quad RE\% = \frac{\sqrt{\sum_{i=1}^n (H_i - \hat{H}_i)^2 / (n-p)}}{\bar{H}} * 100 \quad [1]$$

167

168 Where: H_i , \hat{H}_i y \bar{H} correspond to the observed height values, \hat{H}_i to the predicted height
169 values, and \bar{H} to the average dominant height; n is the number of observations and p the number
170 of model parameters. The base age is selected within the range of relative error showed by the
171 lowest and the highest number of observations.

172

173 *Model selection and evaluation criteria*

174

175 The evaluation of each model was based on the indicators of goodness of fit, predictive
176 capabilities and graphical analysis of residuals (Table 3). These indicators included the
177 coefficient of determination r^2 (calculated as the square of the correlation coefficient between the
178 observed and estimated dominant height), the standard error of the estimate, the mean square
179 error (REMC), the residual standard deviation (RSD), the aggregate difference (DIFA) plus the
180 Akaike information criterion (AIC) and the maximum likelihood value (log-likelihood) (Haywood
181 2009, Kitikidou et al. 2012). For validation of the growth functions we performed the
182 Kolmogorov-Smirnov test with an independent sample of 20% of all recorded data ($p < 0.01$).

183 Characterization of differences between edaphoclimatic zones followed Alvarez et al.
184 (2004), Calama et al. (2003), and Kitikidou et al. (2012) by evaluating the need of specific
185 models for each zone with the corresponding F statistic test [2] (Bates and Watts 1988, Kitikidou
186 et al. 2012).

187

$$188 \quad F = \frac{SSE(R) - SSE(C)}{df_r - df_c} \bigg/ \frac{SSE(C)}{df_c} \quad [2]$$

189

190 Where: SSE is the sum of squares of error; df are the degrees of freedom of the model;
191 C corresponds to the full model; R is the reduced model; and F follows a Snedecor F distribution.

192

193 **Results**

194

195 ***Model selection and validation***

196

197 In each edaphoclimatic zone (Table 3), the adjusted model parameters were highly
198 significant ($p < 0.01$). The measures of goodness of fit and predictive capabilities showed few
199 differences for each tested model. In edaphoclimatic zone 1 we rejected the use of the logistic
200 model because it showed greater errors in these measures. Instead, the Chapman-Richards and
201 Weibull models showed fewer differences, but the Chapman-Richards model had a lower bias in
202 the estimates and showed the best results for every zone.

203

204 **Table 3**

205

206 The validation of the selected models showed no significant differences between the
207 observed and modeled data. Therefore it is assumed that the models allow modeling dominant
208 height in secondary forests for trees that range between 10 and 60 years of age.

209 The mean curves for each edaphoclimatic zone (Figure 2) show differences starting at age
210 35, with the curve corresponding to zone 2 being the one that achieves a higher dominant height
211 growth at the end of the observed age for the data set (31 m at 60 years). The lowest growth
212 corresponded to zone 3 (24 m at 60 years), while zone 1 (29 m at 60 years) was intermediate in
213 average height growth. Notably the asymptote of zone 3 falls steeply compared to zones 1 and 2.

214 The relative error is minimized between 30 and 40 years, so we set a base age of 35 years for
215 each edaphoclimatic zone.

216 Comparison of growth patterns between edaphoclimatic zones (Table 4) showed
217 significant differences ($p < 0.05$). Therefore the null hypothesis of a single model of productivity
218 for the three edaphoclimatic zones is rejected, which highlights the need to consider a model of
219 age-top height for each zone.

220

221 **Figure 2**

222

223 Comparison of growth patterns between edaphoclimatic zones (Table 4) showed
224 significant differences ($p < 0.05$). Therefore the null hypothesis of a single model of productivity
225 for the three edaphoclimatic zones is rejected, which highlights the need to consider a model of
226 age-top height for each zone.

227

228 **Table 4**

229

230 *Site index curves for each edaphoclimatic zone*

231

232 Model estimates for site index and dominant height curves for each edaphoclimatic zone
233 showed different asymptote values (Table 5), reflecting differences in productivity for each zone.
234 The results showed that the area with higher potential of height growth at age 60 occurred for
235 zone 2 followed by zone 1 and zone 3.

236

237 **Table 5**

238 **Figure 3**

239

240 **Discussion**

241

242 This study is the first to represent at a regional scale the productivity of *N. dombeyi*
243 secondary forests. Previously there is a study by Esse et al. (2007) that developed site index
244 curves for one specific area in the Andes of south-central Chile. Similarly, several site index
245 curves have been developed by other authors for specific areas for other *Nothofagus* species
246 (Martínez Pastur et al. 1997, Trincado et al. 2002, Salas and García 2006, Ivancich et al. 2011).
247 Considering the great ecological importance and economical potential of these *Nothofagus*
248 forests, it seems of high priority to start developing regional studies of site index for species of
249 this genus and for other economically important species. This process is stronger if it is
250 accompanied by an identification of the physical factors that determine the behavior of dominant
251 height in a given species. In this sense, this work enable validate the study of Esse et al. (2013)
252 who defined edaphoclimatic zones for secondary forests of *N. dombeyi* based on climatic, soil
253 and topographic factors and the main variables within them. Results showed that all three models
254 statistically differed. This means that each zone required a single model for estimating dominant
255 height. Of the three zones, two have a similar high site index at age 35 (22 and 23 m) and one has
256 a lower site index (20 m). These site indices are higher compared with those for *N. obliqua* in a
257 nearby region, which ranged between 24 and 30 m at age 50 (Salas and García 2006).

258 The high variability of dominant height growth can be an effect of site quality as affected
259 by edaphoclimatic factors and variables like those described by Esse et al. (2013). Differences
260 could also be explained, however, by variable stem density that these stands may have had in the
261 past. Although tree height is usually quite independent of stand tree density, some studies have

262 shown that there are some exceptions (Menziés et al. 1989, Mason 1992). In the case of *N.*
263 *dombeyi* secondary forests, these have the higher stand density indices among *Nothofagus* species
264 in Chile and Argentina (Chauchard et al. 1999 and 2001, Esse et al. 2007, Gezán et al. 2007). The
265 stands measured in this study showed very high densities (up 4,000 tree ha⁻¹), generally had large
266 number of dead and suppressed trees, and therefore we do not believe that stand densities
267 affected height growth.

268 Growth curves were very variable (6 to 23 meters) before reaching the age base (Figure
269 3). Edaphoclimatic zone 3 had the lowest growth, where the curve of greatest productivity at the
270 base age reached 22 meters and only 24 m at age 60 years, with an asymptote developing
271 around age 40. For this zone, the lowest growth curve reached only 6 m height at the base age,
272 and 12 m for the mean curve. The best growth rates occurred in zone 2 with trees that reached 23
273 meters of height at the base age and 31 meters of height projected at age 60 years. Zone 1 had
274 dominant trees reaching 20 m height at 35 years old and 29 m in height projected at age 60. These
275 results are similar to those found by Salas and García (2006), Trincado et al. 2002 and Ivancich et
276 al. (2011) in other *Nothofagus* species in terms of a high variability in dominant tree height
277 between and within sites.

278 The selection of the Chapman-Richards model showed, like similar studies (García 1983,
279 Ker and Bowling 1991, Esse et al. 2007), that this model allows a good representation of tree
280 growth and all the parameters with enough sensitivity to site factors. This statement is based on
281 the statistical test results of the extra sum of squares (Table 4) which showed that stands of *N.*
282 *dombeyi* grow under the effect of site factors characteristic of each zone. This result allowed us to
283 validate the proposed zoning by Esse et al. (2013), who defined soil and climatic zones for *N.*
284 *dombeyi* through spatial analysis based on a set of biophysical variables related to climatic, soil
285 and topographical factors, which influence growth and further development of this species. As a

286 result of the model validation, it is recommended that they should be applied in stands with ages
287 between 10 and 60 years. This result, like others (Clutter et al. 1983, Carrero et al. 2008,
288 Kitikidou et al. 2012), shows that growth models and site productivity have adjustment problems
289 for their curves at early ages of development, so that the range of applications of these should be
290 clearly defined.

291 Esse et al. (2007) used a base age to 40 years for secondary forests of *N. dombeyi* in the
292 pre-Andean region of Araucania, Chile. Ivancich et al. (2011) suggest base ages ranging between
293 20-60 years for *Nothofagus* forests on the bases of a literature review. Considering that *N.*
294 *dombeyi* rotations should be close to 70 and 80 years (Donoso et al. 1999), the base age selected
295 in the present study can be considered near the middle of the rotation age, a convenient age as
296 suggested by Bailey and Clutter (1974).

297 The yielded information on productivity for secondary forests dominated by one of the
298 most important native tree species in southern Chile is relevant for forestry development projects,
299 for potentially differential assignment of current subsidies for silvicultural practices in these
300 forests, and for land use planning. These issues should substantially contribute to sustainable
301 management of natural species whose growth characteristics and productivity have shown their
302 high potential for forestry.

303

304 **Conclusions**

305

306 The results show the requirement for one dominant height model for each of the
307 edaphoclimatic zones. This demonstrates the great variability of sites characteristics where *N.*
308 *dombeyi* grows.

309 There is a great variability in site index in *N. dombeyi* secondary forests and dominant tree
310 height of this species, both among and within the three edaphoclimatic zones evaluated in the
311 foothills and mountains of the Andes in south-central Chile. These variations are expressed at the
312 base age evaluated and also when projected at age 60, i.e. close to rotation age for these forests.
313 In general, however, the height growth of this species, especially in zones 1 and 2, is much higher
314 than that observed for other *Nothofagus* species in South America, reflecting the high
315 productivity previously reported for forest stands dominated by *N. dombeyi*.

316 Our results that indicated the need to develop different site index equations for three
317 edaphoclimatic zones defined in a previous, the which validates the previous zoning and
318 illustrates the convenience to define these zones prior to defining site index equations. This type
319 of studies is a contribution for the decision-making process, both for individual landowners and
320 for public institutions.

321

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323

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330

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332

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448 **Table 1.** Summary description of the trees sampled for stem analyses in each edaphoclimatic
449 zone.

Zona	N° of trees	Age mean	S.D.	Age min	Age max	Height mean	S.D	Height min	Height max	N (tree ha ⁻¹)	AB (m ² ha ⁻¹)	QSD (cm)
1	98	46.5	6.2	35.0	60.0	19.0	2.3	10.5	24.0	2050	51.24	19.10
2	46	47.6	10.4	23.0	59.0	18.0	3.4	7.7	24.0	1370	36.82	19.22
3	96	48.7	7.7	31.0	60.0	17.4	3.4	10.8	26.0	1664	41.27	19.40

450 QSD: Quadratic Stand Diameter (cm)

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469 **Table 2.** Candidate functions for modeling dominant height.

Model	Name	Function	Diferencial model
1	Chapman-Richards	$H = a(1 - e^{-bE})^c$	$H_2 = a \left[1 - \left[1 - \left(\frac{H_1}{a} \right)^{\frac{1}{c}} \right]^{\frac{E}{E_b}} \right]^c$
2	Logístico	$H = a/(1 + ce^{bE})$	$H_2 = \frac{a}{\left[(1 + c) \left[\left(\frac{a}{H_1} \right) - 1 \right] / c \right]^{\frac{E}{E_b}}}$
3	Weibull	$H = a(1 - e^{-bE^c})$	$H_2 = a \left[1 - \left[1 - \left(\frac{H_1}{a} \right) \right]^{\left(\frac{E}{E_b} \right)^c} \right]$

470 Symbology: a, b, c parameters to be estimated; H height; E age; E_b base age.

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485 **Table3.** Measures of goodness of fit and predictive capabilities for each model in each
 486 edaphoclimatic zone.

Zone	Model	r^2	REMC	%REMC	RSD	%DIFA	AIC	Log-Link	SE	Parameter	$p > t $
										$a=34.6990$	
	1	0.88	2.02	27.89	4.10	-0.28	3793.39	-1892.69	2.028	$b=0.02626$ $c=1.94454$	<.0001
										$a=21.2741$	
1	2	0.87	2.09	28.49	4.37	-1.46	3852.44	-1922.22	2.096	$b=-0.1040$ $c=23.0854$	<.0001
										$a=27.3500$	
	3	0.88	2.02	27.85	4.10	-0.35	3791.72	-1891.86	2.026	$b=0.00156$ $c=1.69200$	<.0001
										$a=36.6771$	
	1	0.85	2.26	26.88	5.13	-0.94	1461.87	-726.93	2.276	$b=0.01889$ $c=1.44887$	<.0001
										$a=20.9683$	
2	2	0.83	2.45	28.81	5.97	-1.73	1512.33	-752.16	2.460	$b=-0.0915$ $c=14.4866$	<.0001
										$a=33.7500$	
	3	0.85	2.27	26.90	5.14	-1.06	1463.14	-727.57	2.280	$b=0.00434$ $c=1.32100$	<.0001
										$a=24.8937$	
	1	0.83	2.26	34.56	5.11	-0.32	3985.68	-1988.84	2.265	$b=0.03725$ $c=2.16506$	<.0001
										$a=18.4592$	
3	2	0.82	2.34	35.34	5.47	-0.32	4048.62	-2020.31	2.346	$b=-0.1140$ $c=21.9175$	<.0001
										$a=21.8100$	
	3	0.83	2.27	34.51	5.13	-0.66	3989.56	-1990.78	2.270	$b=0.00192$ $c=1.71700$	<.0001

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491 **Table 4.** Model comparison for each edaphoclimatic zone (test F-Snedecor).

Paired comparison	SCE_T	SCE_1	SCE_2	Full model	Reduced model	F
$Z_1 - Z_2$	691,94	413,44	249,59	0,55	9,64	17,55
$Z_1 - Z_3$	926,80	413,44	496,34	0,51	5,67	11,07
$Z_2 - Z_3$	779,13	249,59	496,34	0,62	11,07	17,90

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512 **Table 5.** Model estimates of site index and dominant height for each edaphoclimatic zone.

Zone	Site index model
1	$H = 34.699067 \left[1 - \left[1 - \left(\frac{SI}{34.699067} \right)^{\frac{1}{1.944544}} \right]^{\frac{E}{35}} \right]^{1.944544}$ $SI = 34.699067 \left[1 - \left[1 - \left(\frac{H}{34.699067} \right)^{\frac{1}{1.944544}} \right]^{\frac{35}{E}} \right]^{1.944544}$
2	$H = 36.677176 \left[1 - \left[1 - \left(\frac{SI}{36.677176} \right)^{\frac{1}{1.448875}} \right]^{\frac{E}{35}} \right]^{1.448875}$ $SI = 36.677176 \left[1 - \left[1 - \left(\frac{H}{36.677176} \right)^{\frac{1}{1.448875}} \right]^{\frac{35}{E}} \right]^{1.448875}$
3	$H = 24.893745 \left[1 - \left[1 - \left(\frac{SI}{24.893745} \right)^{\frac{1}{2.16506}} \right]^{\frac{E}{35}} \right]^{2.16506}$ $SI = 24.893745 \left[1 - \left[1 - \left(\frac{H}{24.893745} \right)^{\frac{1}{2.16506}} \right]^{\frac{35}{E}} \right]^{2.16506}$

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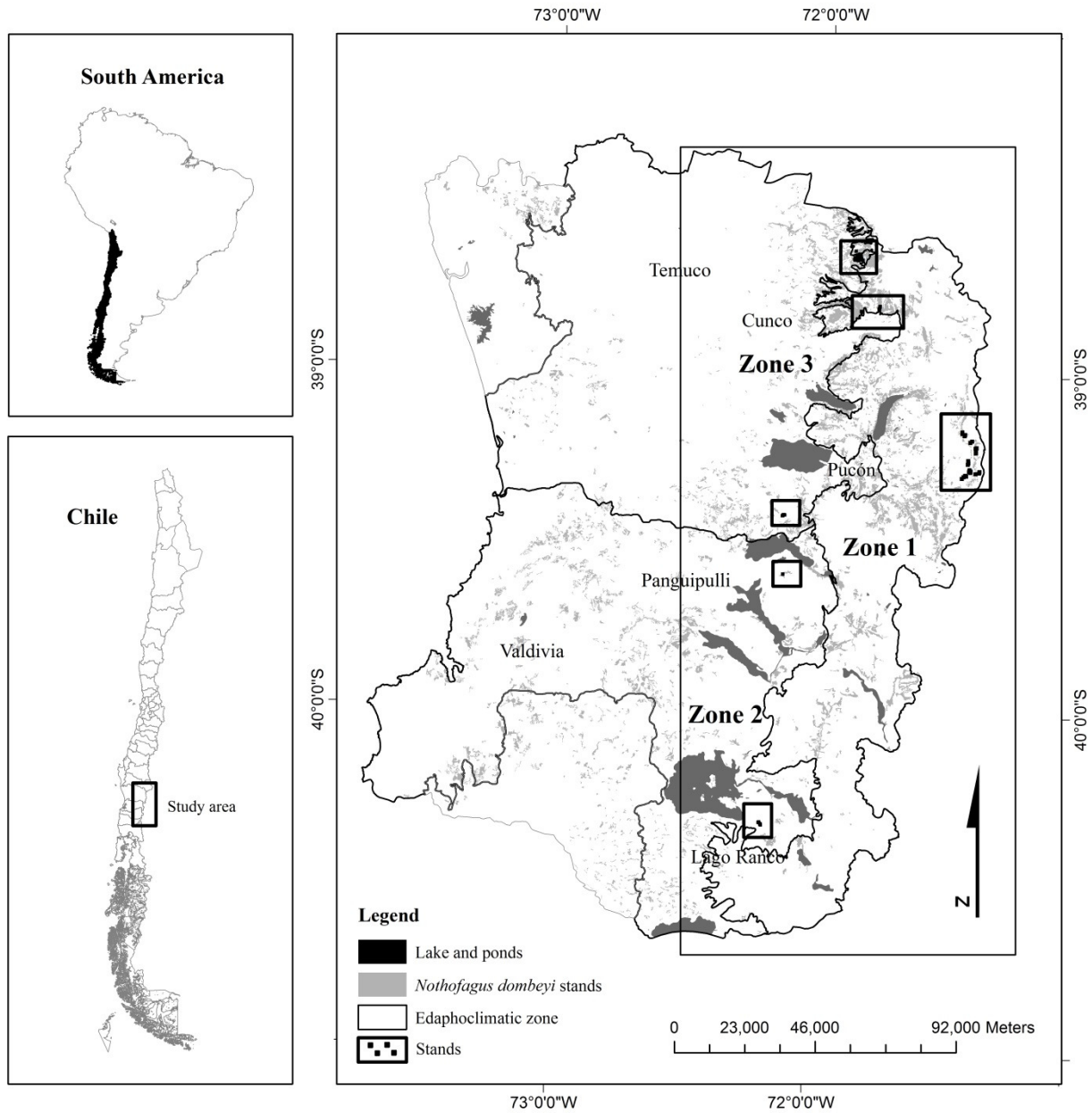
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527 **Figure 1.** Study area illustrating the edaphoclimatic zones defined by Esse et al. (2013) and for
 528 which site index and dominant height models were tested.

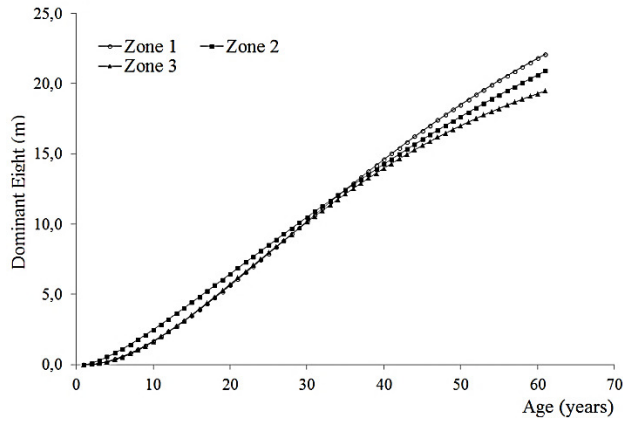
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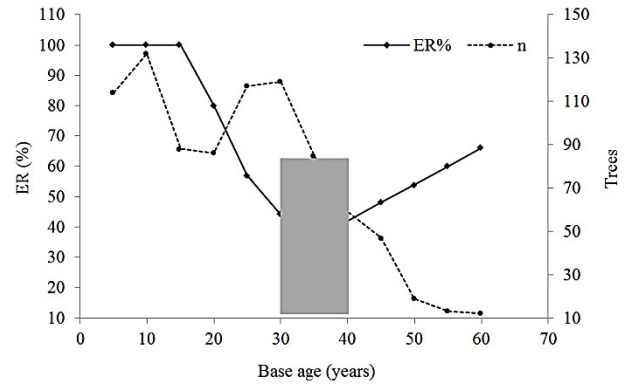
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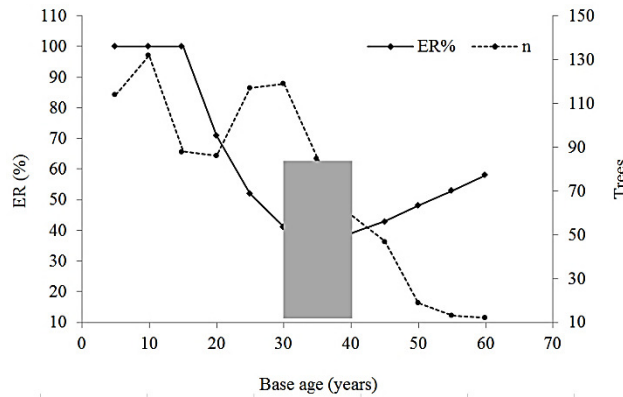
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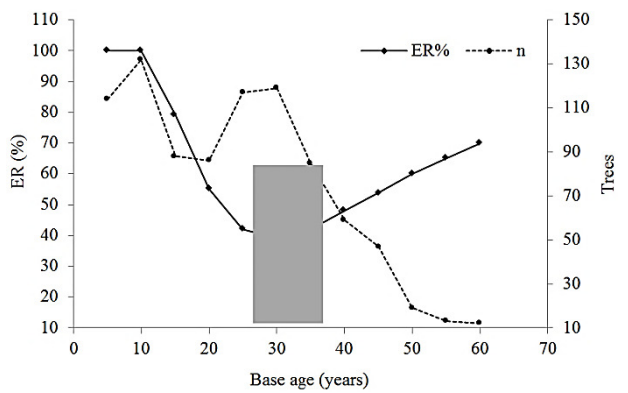
b.)



c.)



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534 **Figure 2.** Average curves for modeling dominant height depending on the age and relative error

535 graph for defining base age. a) mean curve by zone; b) relative error for zone 1; c) relative error

536 for zone 2; d) relative error for zone 3.

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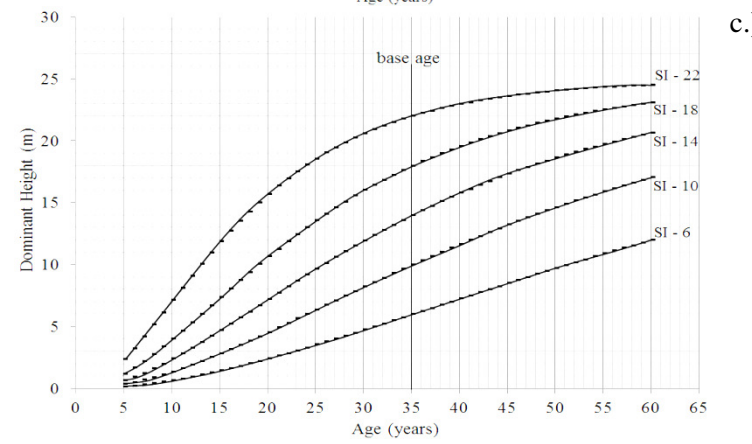
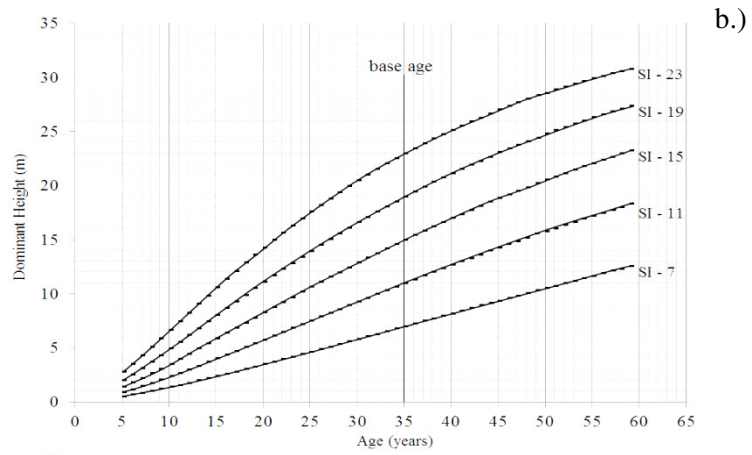
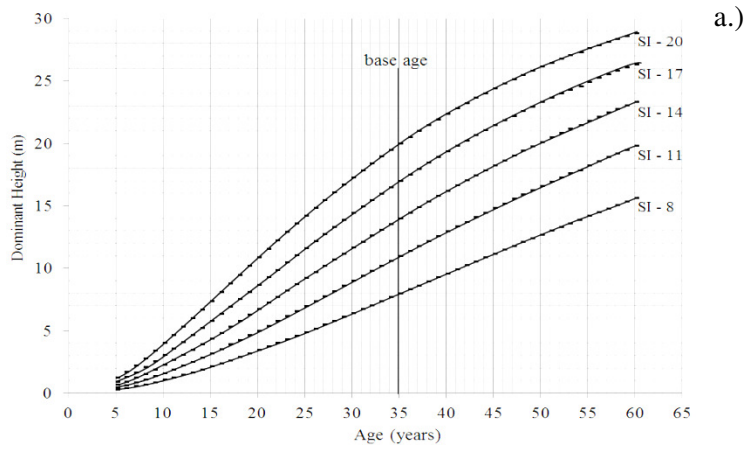
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544 **Figure 3.** Site index curves for each edaphoclimatic zone. a) zone 1, b) zone 2, c) zone 3.