



Stocking guide for *Pinus occidentalis* Swartz: tree area ratio and crown allometry approach

Running head: Stocking guide for *Pinus occidentalis*

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Abstract

Introduction. Stand density management is a vital component of sustainable pine silviculture, particularly in tropical montane forests, where growth patterns and self-thinning processes differ from those in temperate systems. For *Pinus occidentalis* Swartz, the endemic pine of Hispaniola, locally tailored density guidelines remain



absent, thereby restricting the use of quantitative thinning and restoration strategies.

Objective. To develop a locally calibrated stocking guide for *P. occidentalis* by deriving the upper self-thinning boundary (A-line) and the lower management boundary (B-line), and to evaluate their implications for stand-density management.

Materials and methods. Forest inventory data from natural *P. occidentalis* stands covering a broad range of ages, site conditions, and stand densities were examined. Self-thinning relationships were modelled using stand density and quadratic mean diameter to establish the A-line, while the B-line was set as a fixed proportion of the A-line based on established density-management principles. Model performance was assessed through statistical goodness-of-fit and biological plausibility.

Results. The final A-line model demonstrated a strong and biologically consistent size–density relationship, establishing the maximum density limit for *P. occidentalis* stands. The derived B-line identified a practical lower threshold for active management. Together, these boundaries defined a density management zone corresponding to moderate stand densities, offering clear criteria to classify stands as overstocked, optimally stocked, or understocked.

Conclusions. This study introduces the first locally developed A-line–B-line stocking guide for *P. occidentalis*, providing a quantitative framework to aid thinning, restoration, and the sustainable management of Dominican pine forests.

Keywords: density management, maximum stand density, crown width, carrying capacity, self-thinning.

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Introduction

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Stand density management is a fundamental component of silviculture because it regulates competition for growing space, influences tree growth and mortality, and underpins decisions related to thinning, yield regulation, and stand stability (Burkhart et al., 2018). Density guides are widely used tools that synthesize key stand variables—such as tree density, basal area, and quadratic mean diameter—into a graphical framework that supports practical decision-making in forest management (Baral, 2017; Hernández-Martínez et al., 2024). By delineating zones of overstocking, optimal stocking, and understocking, density guides help managers evaluate current stand conditions and plan interventions that promote efficient use of site resources (Ray et al., 2023).

The conceptual foundation of stocking guides is rooted in classical size–density relationships, which describe how maximum stand density declines predictably as mean tree size increases. Reineke’s size–density relationship, expressed through the stand density index, and Gingrich’s stocking charts based on basal area and tree density remain cornerstone approaches in silviculture (Gingrich, 1967; Reineke, 1933). These methods combine stand density, basal area, and quadratic mean diameter to define upper and lower density boundaries—commonly referred to as A-lines and B-lines—that frame a density management zone. Subsequent developments have refined these concepts by incorporating biologically meaningful measures of competition, particularly crown attributes that more directly represent growing space occupancy (Burkhart et al., 2018).

Modern stocking guides continue to evolve as dynamic tools that integrate empirical data, species-specific relationships, and site conditions, allowing them to adapt to changing environmental and management contexts (Carson et al., 2023). Their standardized and visual nature facilitates communication among foresters, landowners, and other stakeholders, improving transparency and consistency in



30 silvicultural planning (Pretzsch, 2009; Ray et al., 2023). Assessing stand density
31 using relative measures derived from size–density theory has become especially
32 valuable for guiding thinning intensity, reducing mortality risk, and optimizing
33 growth efficiency across a wide range of forest types (Looney & Shaw, 2025).

34 Despite the widespread application of density management diagrams worldwide,
35 species- and region-specific stocking guides remain necessary because self-
36 thinning dynamics, crown architecture, and competitive interactions vary among
37 species and ecological settings (Yang & Brandeis, 2022). *Pinus occidentalis*
38 Swartz, an endemic conifer of Hispaniola and a dominant species in the montane
39 pine forests of the Dominican Republic, plays a critical ecological and silvicultural
40 role. These forests are characterized by relatively open understories with limited
41 herbaceous cover (*Melinis minutiflora* P. Beauv., *Parthenium hysterophorus* L.,
42 and *Cyathea* spp.) and scattered shrubs (*Eysenhardtia polystachya* [Ortega] Sarg.
43 and *Pithecellobium unguis-cati* L. Benth), reflecting the strong influence of canopy
44 structure on resource availability (Bueno-López et al., 2024). Although *P.*
45 *occidentalis* is central to forest conservation, restoration, and sustainable
46 management initiatives in the region, no locally calibrated stocking guide currently
47 exists for this species (Bueno-López et al., 2024). Therefore, limits the application
48 of quantitative, science-based density management in Dominican pine forests.

49 The objective of this study was to develop a species-specific stocking guide for *P.*
50 *occidentalis* in La Sierra, Dominican Republic, by defining the upper density
51 boundary using a tree area ratio model and the lower management threshold using
52 crown–diameter allometry, and integrating these into a practical stocking chart for
53 silvicultural decision-making.

54 We hypothesized that: (H1) maximum stand density of *P. occidentalis* follows a
55 predictable size–density relationship that can be quantified using a tree area ratio
56 model; and (H2) crown–diameter allometry of open-grown trees defines a
57 biologically meaningful lower density threshold corresponding to crown closure
58 and management occupancy.

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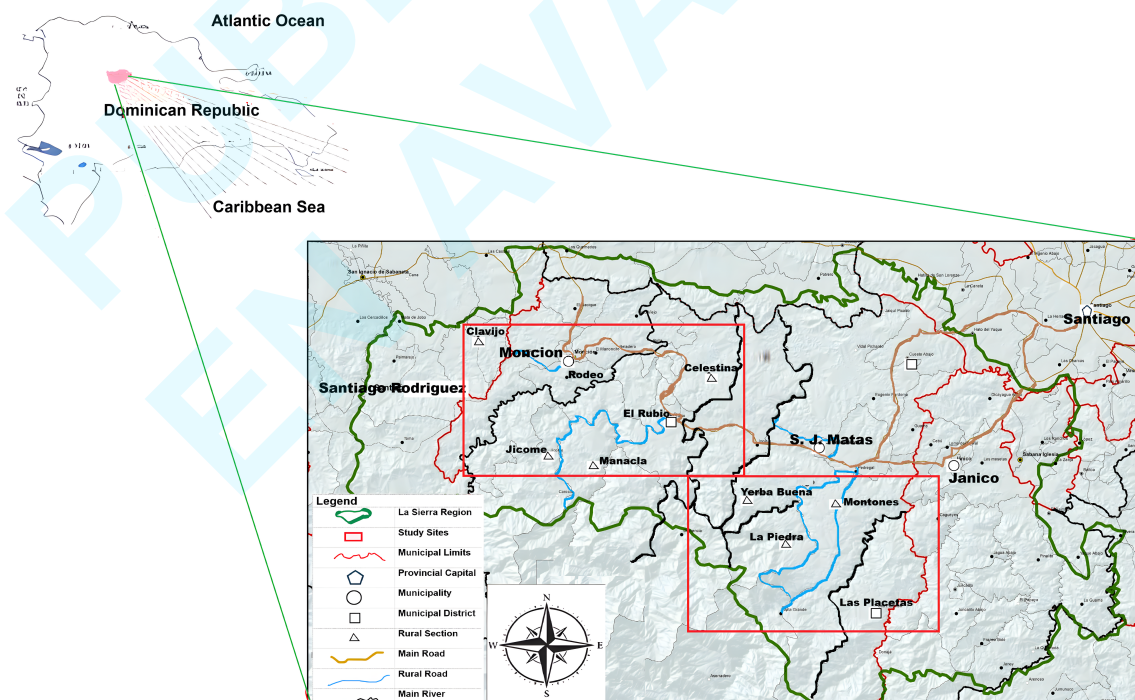
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Materials and methods

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64 The study was conducted in La Sierra, Dominican Republic. La Sierra is located
65 between UTM coordinates 251748 m E - 325795 m E and 2116888 m N - 2156996
66 m N, within the northcentral portion of Cordillera Central (Figure 1). It
67 encompasses an area of 1 800 km². Its climate varies depending on the altitude
68 (from low montane to montane) and precipitation (from wet to very wet). Elevations
69 above sea level range between 500 and 1 600 m. Although irregular, rains manage
70 to maintain a certain level of moisture in the soil for a large part of the year. Average
71 annual precipitation ranges from 800 mm to 1 600 mm, with an average annual
72 temperature of approximately 24 °C (Bueno-López et al., 2024). The pine forests
73 on these higher elevation slopes typically develop in shallow, carbonate, lateritic,
74 low-productivity soils, located primarily on land with rugged topography, with more
75 than 90 % of the area being mountainous, and slopes varying from 0 % to 70 %.



76



77 **Figure 1.** Projection of La Sierra region in the Dominican Republic.

78 Soils have a sandy texture, although higher proportions of clay and silt can be
79 observed in some places. They are usually well drained, and where the surface is
80 well protected by vegetation, fertility increases.

81 Descriptive statistics of stand attributes used to construct the stocking guide for *P.*
82 *occidentalis* are presented in **Table 1**. These values summarize the structural
83 conditions of sample plots across La Sierra, providing the empirical basis for
84 defining the A-line and B-line boundaries of the stocking chart.

85 To create the stocking chart for *P. occidentalis* in La Sierra, we followed the
86 methodological framework used by Halligan and Nyland (1999) for developing a
87 relative density guide for *Picea abies* (L.) H. Karst. Their method was based on the
88 foundational works of Gingrich (1967) and Krajicek et al. (1961), which outlined the
89 core concepts of stand density relationships and relative density guides. This
90 approach connects tree size, density, and basal area in a meaningful biological
91 way, enabling clear definitions of full stocking, understocking, and overstocking
92 thresholds.

93 We examined the quantitative relationships between stand density, tree size, and
94 basal area. Using this established method ensured that the stocking chart for *P.*
95 *occidentalis* was created consistently and in accordance with widely accepted
96 standards, making it easier to compare with stocking guides for other species and
97 forest types.

98 The A-line, which marks the upper limit of stand density, was derived from 52 plots
99 and features relatively small tree diameters typical of crowded conditions.
100 Permanent sample plots were fixed-area plots of 25 m × 25 m (equivalent to 0.0625
101 ha), established within even-aged stands of *P. occidentalis*. Plot size was selected
102 to adequately capture stand structure and variability in tree density, diameter
103 distribution, and crown dimensions across the study area. Plots were allocated
104 using a stratified approach to capture the diversity of stand conditions in *P.*
105 *occidentalis* forests within the study area. Candidate stands were chosen based



106 on species dominance, even-aged structure, and accessibility. Within these
107 stands, plot locations were carefully selected to avoid edge effects and local
108 disturbances, ensuring that the measured plots accurately reflected prevailing
109 stand conditions. For each plot, the following variables were recorded or derived:
110 Tree density (N , trees·ha⁻¹), sum of diameters at breast height (SUMD, cm), sum
111 of squared diameters (SUMDD, cm²), basal area (m²·ha⁻¹), and quadratic mean
112 diameter (QMD, cm). Basal area (BA) was computed as:

$$113 \quad BA = [\pi / (4 \times 10\,000)] \times N \times QMD^2$$

114 From this dataset, the A-line, also known as the maximum average density line
115 (Gingrich, 1967), was calculated using the Tree Area Ratio (TAR) regression
116 model:

$$117 \quad TAR = \beta_0 N + \beta_1 SUMD + \beta_2 SUMDD$$

118 The average diameter at breast height (DBH) was 22.89 cm, and the QMD was
119 23.97 cm. Stand density averaged 884 trees·ha⁻¹, varying from 400 to 2 400, while
120 the average stand basal area was 35.80 m²·ha⁻¹, with a minimum of 16.95 and a
121 maximum of 82.70 m²·ha⁻¹. These figures illustrate the range of stand structures
122 observed near maximum site occupancy.

123 Additionally, a supplementary dataset of 30 open-grown trees was used to
124 construct the Maximum Crown Area (MCA) occupancy line, also known as the
125 minimum density line (Krajicek et al., 1961), hereafter referred to as the B-line. For
126 each tree, DBH and crown width (m) were measured to analyze the crown–
127 diameter relationship, yielding the B-line from these crown allometry data, which
128 relates crown width to DBH. The average crown width was 9.47 m, ranging from
129 6.90 to 12.55 m, while the mean DBH was 40.24 cm, with a range from 23.00 to
130 57.90 cm.

131 **Table 1.** Descriptive statistics of stand structural attributes used to construct the
132 stocking guide for *Pinus occidentalis* in La Sierra, Dominican Republic.

Chart attribute	n	Variables	Mean	SD	Minimum	Maximum
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A-Line	52*	Average DBH (cm)	22.89	6.68	10.33	38.86
		Quadratic mean diameter (cm)	23.97	6.73	11.27	39.67
		Stand density (trees·ha ⁻¹)	884	462	400	2 400
		Stand basal area (m ² ·ha ⁻¹)	35.80	14.86	16.95	82.70
B-Line	30**	Crown width (m)	9.47	1.68	6.90	12.55
		Average DBH (cm)	40.24	8.20	23.00	57.90

133 *Plots; **Open-grown trees. DBH: diameter at breast height, SD: Standard deviation.

134

135

136 Construction of the A-line and B-line

137

138

139 The upper boundary of maximum stand density (A-line) was developed using the
140 tree area ratio (TAR) regression model:

$$141 \quad TAR = \beta_0 N + \beta_1 SUMD + \beta_2 SUMDD$$

142 where TAR represents the average growing space per tree (m²·tree⁻¹), SUMD is
143 the sum of tree diameters at breast height (cm), and SUMDD is the sum of squared
144 diameters (cm²). Coefficients were estimated from the plot-level inventory data,
145 and predictions were made for QMD values ranging from 12 to 48 cm. With N set
146 to 1, stand density was calculated as:

$$147 \quad TPH = 1\,000 / TAR$$

148 where TPH is trees per hectare. Basal area (BA, m²·ha⁻¹) was then calculated for
149 each assumed QMD as:

$$150 \quad BA = 0.00007854 * TPH * QMD^2$$

151 The B-line was derived from crown–diameter relationships. A linear regression was
152 first fit between crown width (CW, m) and tree diameter (D, cm):



153
$$CW = \alpha_0 + \alpha_1 D$$

154 Maximum crown area (MCA), expressed as a percentage of one hectare, was
155 estimated as:

156
$$MCA = [\pi / (4 * 100)] * CW^2 \approx 0.00785398CW^2$$

157 Substituting the fitted crown–diameter regression, MCA was expressed as:

158
$$MCA = 0.00785398 (\alpha_0 + \alpha_1 D)^2$$

159 For each QMD value, tree density was computed as $N = 100 / MCA$, and basal
160 area was recalculated as described above. The predicted values from these
161 procedures formed the A-line (full site occupancy line) and B-line (MCA occupancy
162 line), which together define the upper and lower density limits for the *P.*
163 *occidentalis* stocking chart.

164

165

166 **Stocking Chart Construction and Visualization**

167

168

169 The predicted values of N and BA corresponding to each QMD were used to create
170 the stocking chart. The A-line was plotted as the upper boundary, representing the
171 maximum size–density relationship, while the B-line served as the lower boundary,
172 indicating the management threshold. Both lines were drawn with N on the x-axis
173 and BA on the y-axis, providing a visual framework for assessing stand density in
174 *P. occidentalis*. This chart functions as a practical tool for identifying overstocked
175 and understocked conditions and for guiding silvicultural interventions across the
176 species' natural range in La Sierra.

177 Computations were carried out using IBM SPSS Statistics (version 27; IBM Corp.,
178 2020) and Microsoft Excel (Microsoft Corporation, 2018), which were employed for
179 statistical analyses, data visualization, and spreadsheet-based calculations. These



180 software platforms provided the necessary tools to conduct descriptive statistics,
181 regression modeling, and organize stand-level datasets in support of stocking
182 guide construction.

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184

185 Results and discussion

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188 Stands with high density and small QMD ($\approx 11\text{--}13$ cm; $>2\,000$ trees $\cdot\text{ha}^{-1}$) reached
189 only moderate basal areas ($\approx 25\text{--}30$ m $^2\cdot\text{ha}^{-1}$). In contrast, lower-density stands
190 ($\approx 400\text{--}800$ trees $\cdot\text{ha}^{-1}$) with larger trees (QMD 30–35 cm) accumulated much greater
191 basal areas (60–80 m $^2\cdot\text{ha}^{-1}$). The TAR regression explained ~ 90 % of the variation
192 (Adj. $R^2 = 0.90$). Although individual predictors were not statistically significant due
193 to multicollinearity, the model as a whole provided a strong fit. This is expected
194 since SUMD and SUMDD are mathematically related to N. In practical terms, the
195 A-line defines an empirical boundary of maximum stand occupancy rather than
196 testing the independent effects of predictors.

197 These results support hypothesis 1 (H1), which suggests that the maximum stand
198 density of *P. occidentalis* follows a predictable size–density trajectory that can be
199 modeled using a tree area ratio (TAR). The boundary behavior observed confirms
200 that stand structural limits are driven by growing-space constraints rather than
201 independent predictor effects. While individual coefficients were not statistically
202 significant, the overall pattern aligns with classical size–density theory and
203 supports TAR as a useful tool for estimating biological carrying capacity. The
204 crown–diameter regression (Table 2) showed a strong positive linear relationship,
205 with both intercept and slope being highly significant. Diameter explained
206 approximately 58 % of the variation in crown width. On average, a 10 cm increase
207 in DBH resulted in a crown width increase of 1.58 m.



208 **Table 2.** Parameter estimates and model statistics for the A-line regression and
209 the B-line equation relating crown width to diameter in *Pinus occidentalis*.

Chart	Variable	Estimate	Std. Error	t	Pr > t
	N	0.01635	0.39831	0.04	0.970
A-Line	SUMD	0.04030	0.04172	0.97	0.340
	SUMDD	0.00035	0.00093	0.38	0.710
B-Line	Intercept	3.09881	1.01541	3.05	0.005
	Diameter	0.15821	0.02474	6.39	<0.001

210 N: tree density, SUMD: sum of diameters, SUMDD: sum of squared diameters.

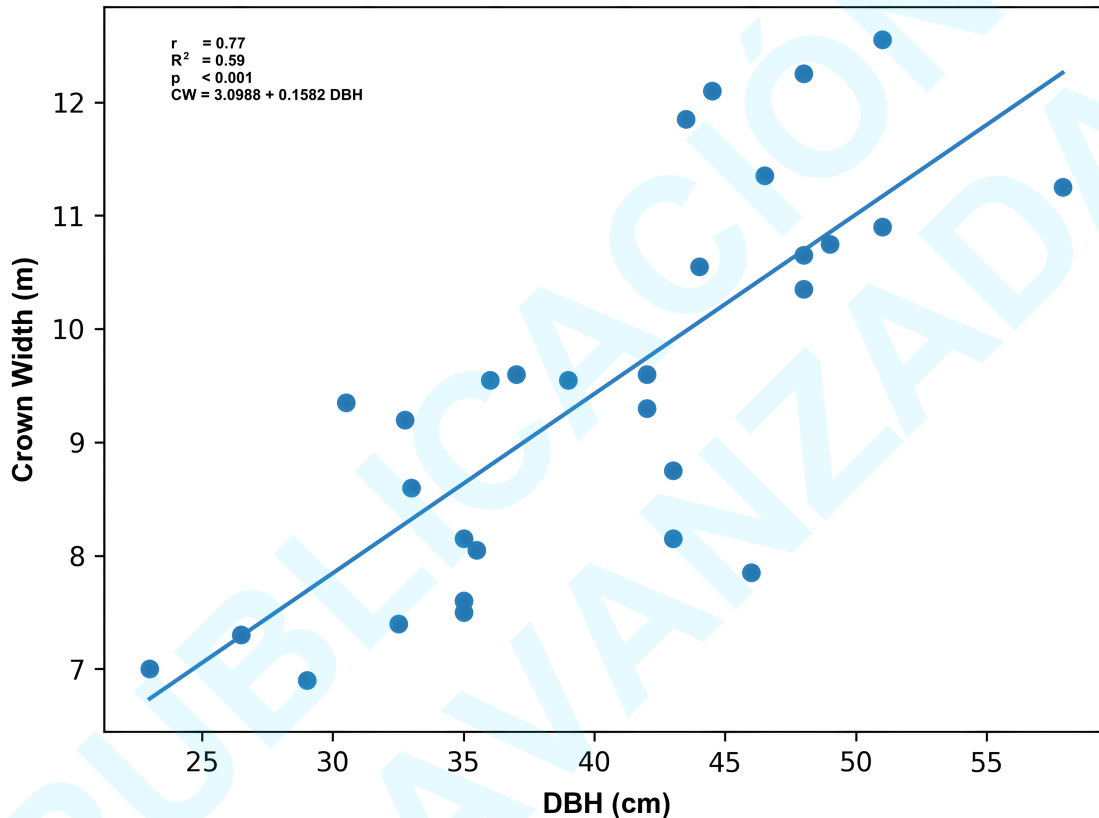
211 While the three independent variables in the A-line model were not individually
212 significant (**Table 2**), this should be understood within the context of stocking-guide
213 methodology. The A-line acts as an empirical upper boundary of maximum stand
214 density, not as a model to test causal effects among predictors (Pretzsch, 2009;
215 Reineke, 1933). Since stand variables like tree density, QMD, and basal area are
216 mathematically and biologically interconnected along the size–density trajectory,
217 multicollinearity is expected. This can decrease the statistical significance of
218 individual coefficients. Consequently, the model was primarily evaluated based on
219 overall performance, biological plausibility, and alignment with size–density theory,
220 rather than the significance of individual parameters.

221 The scatterplot (**Figure 2**) shows a positive relationship between stem diameter
222 and crown expansion for trees used to define the B-line of the stocking guide. As
223 DBH increases, crown width tends to grow, from about 7 m at smaller diameters
224 (~25 cm) to over 12 m at larger diameters (~50-55 cm). This trend reflects how
225 tree size affects canopy development in open-grown conditions, where competition
226 is low and crowns can expand outward. The relationship provides the empirical
227 basis for estimating maximum crown area and, consequently, the minimum fully
228 stocked condition (B-line) in the stocking chart for *P. occidentalis*.

229 This outcome supports hypothesis 2 (H2), suggesting that the relationship between
230 crown size and diameter in open-grown trees indicates a meaningful lower density



231 limit linked to crown closure. The clear positive correlation between DBH and
232 crown width demonstrates *P. occidentalis*'s ability to expand structurally in low-
233 competition conditions, offering a solid basis for estimating the minimum effective
234 stand occupancy. Consequently, the B-line marks a structural shift from underused
235 growing space to complete canopy interaction, rather than an arbitrary boundary
236 for management decisions.



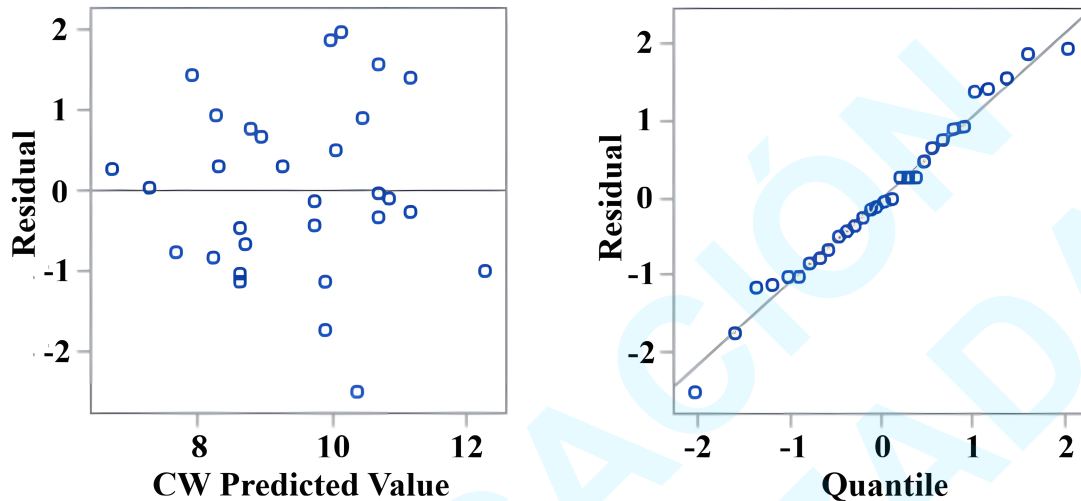
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238 **Figure 2.** Relationship between diameter at breast height (DBH) and crown width
239 in *Pinus occidentalis*. A strong positive correlation was observed (Pearson's $r =$
240 0.77 , $p < 0.001$), indicating increasing crown width with increasing stem diameter.

241 **Figure 3** presents diagnostic plots assessing the regression model used to relate
242 crown width to diameter at breast height (DBH) for constructing the B-line of the
243 stocking guide. The residuals versus predicted crown width values show a random
244 scatter around zero, indicating no significant violation of homoscedasticity or
245 issues with the model fit. The normal quantile–quantile (Q–Q) plot demonstrates



246 that residuals closely follow the expected 1:1 line, supporting the assumption of
247 normality. Overall, these diagnostics confirm that the regression model accurately
248 defines the B-line, which represents the upper limit of crown competition in stand
249 density regulation.



250

251 **Figure 3.** Diagnostic plots for modeling crown width (CW) on diameter at breast
252 height for the B-line guide in *Pinus occidentalis*. Residuals vs. predicted (left)
253 show no pattern, indicating a good fit. The Q–Q plot (right) aligns with the 1:1
254 line, confirming normality.

255 Basal area increased with stand density but was heavily influenced by tree size.
256 The relationship shown in **Figure 4** indicates that basal area generally rises with
257 stand density (trees·ha⁻¹). However, this trend is strongly influenced by tree size,
258 as demonstrated by the point size being proportional to QMD². At low to
259 intermediate densities (below approximately 1 000 N), stands with larger trees
260 (larger QMD² values) contribute disproportionately to basal area, reaching over 60
261 m²·ha⁻¹ despite having relatively few trees.

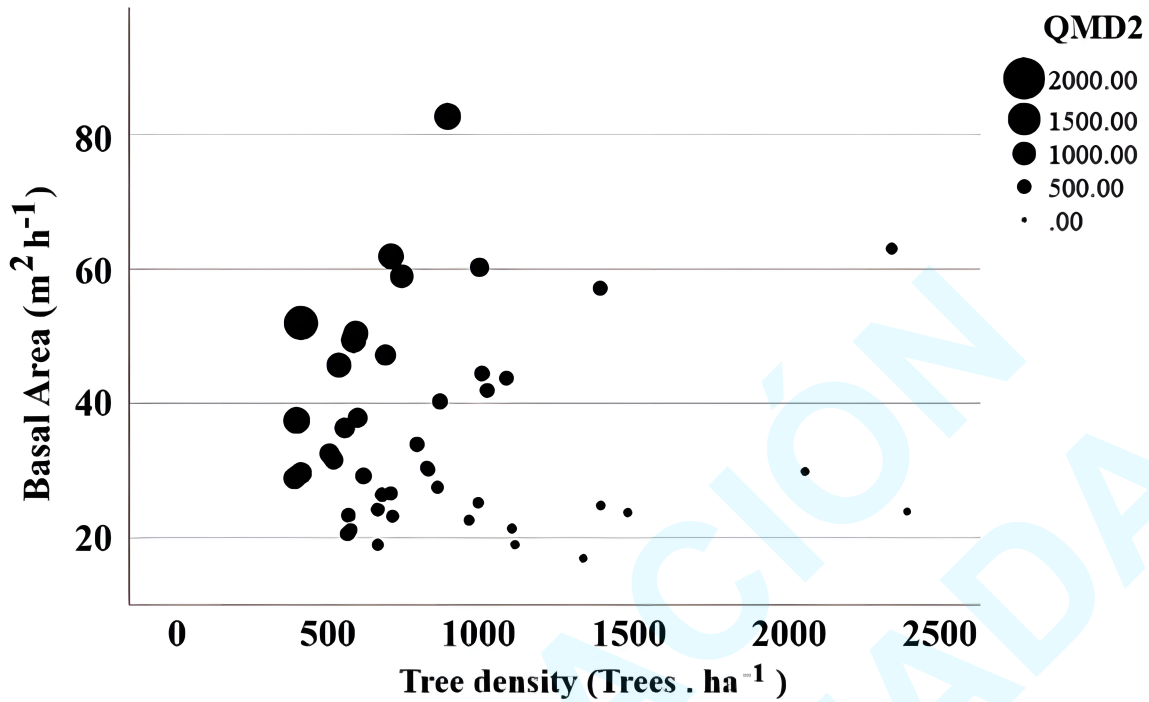
262 Conversely, high-density stands with smaller trees have a relatively low basal area,
263 emphasizing the limited contribution of small trees to total stand biomass. This
264 indicates that while density influences the maximum potential for basal area, the
265 actual stand-level accumulation primarily depends on tree size, with larger trees
266 contributing more to basal area, even at moderate densities. The interaction



267 between density and tree size underscores the importance of considering both
268 structural traits when evaluating stand capacity and competitive interactions.

269 The A- and B-lines together define a critical management window that guides the
270 regulation of stand development. As QMD increases, the widening gap between
271 these lines (Table 3) indicates that the divergence between biological capacity and
272 management limits increases with stand ageing. Early on, density is tightly
273 controlled at smaller diameters, whereas at larger sizes, fewer trees can occupy
274 the same area due to crown growth and competition. This highlights the
275 importance of considering both size–density relationships and crown structure
276 when assessing stand productivity and planning thinning strategies.

277 The relationship between tree density and size directly influences forest
278 productivity, particularly wood volume accumulation. At high stand densities,
279 intense competition for light, water, and nutrients limits diameter growth, leading
280 to many small trees with low merchantable volume despite high stem numbers
281 (Ray et al., 2023; Looney & Shaw, 2025). Conversely, lower stand densities enable
282 individual trees to grow larger and expand their crowns, increasing volume per
283 tree, although this may reduce total stand volume if site utilization is not fully
284 optimized (Burkhart et al., 2018; Gingrich, 1967). Generally, the greatest stand
285 productivity is achieved at intermediate densities, where space is efficiently utilized
286 and both individual growth and stem density are balanced (Langsaeter, 1941; Long
287 & Shaw, 2005). The stocking guide model captures this key trade-off by linking
288 density and tree size to basal area, which serves as a structural indicator of wood
289 volume and overall stand productivity in even-aged forests.



290

291 **Figure 4.** Relationship between basal area and tree density across all plots, with
292 point size proportional to quadratic mean diameter (QMD²), illustrating the
293 dominant effect of tree size on basal area accumulation.

294 **Table 3** demonstrates how stand density (trees·ha⁻¹) and basal area change with
295 QMD along both the A-line and B-line. At smaller diameters (QMD = 12-18 cm),
296 the A-line supports dense stands exceeding 1 100 - 1 800 trees·ha⁻¹, but with
297 moderate basal area (~20-30 m²·ha⁻¹). As QMD increases, stand density
298 decreases steadily (to about 360 trees·ha⁻¹ at 48 cm), while basal area continues
299 to grow, reaching over 65 m²·ha⁻¹. Conversely, the B-line shows significantly lower
300 densities (~110-510 trees·ha⁻¹ across the same QMD range) and lower basal area,
301 reflecting the threshold of crown closure. These trajectories together emphasize
302 the growing gap between biological carrying capacity (A-line) and management
303 occupancy (B-line) as trees become larger.

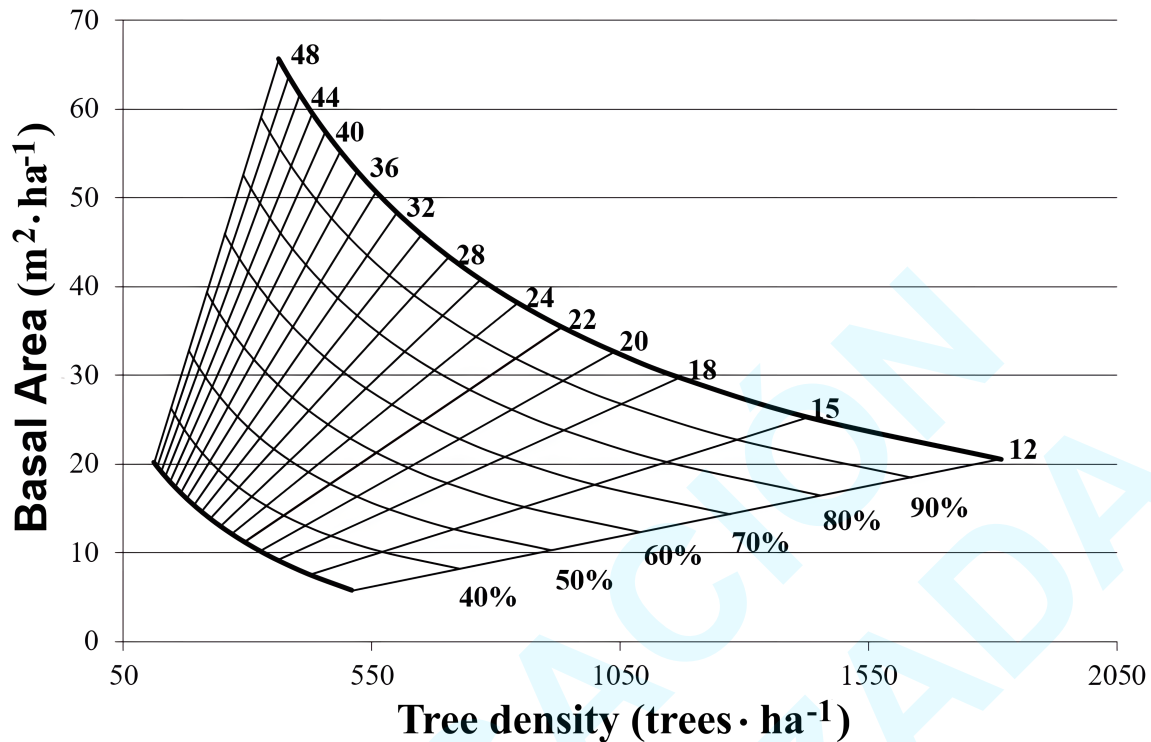
304 **Table 3.** Predicted stand metrics for constructing the A- and B-lines of the *Pinus*
305 *occidentalis* stocking guide, based on quadratic mean diameter (QMD) values
306 from 12 to 48 cm.



A-Line				B-Line			
QMD (cm)	TAR (m ² ·tree ⁻¹)	N (trees·ha ⁻¹)	BA (m ² ·ha ⁻¹)	CW (m)	MCA (% ha)	N (trees·ha ⁻¹)	BA (m ² ·ha ⁻¹)
12.00	0.55	1 817	20.55	5.00	0.20	509.84	5.77
15.00	0.70	1 429	25.26	5.47	0.24	425.23	7.51
18.00	0.86	1 169	29.76	5.95	0.28	360.06	9.16
20.00	0.96	1 039	32.64	6.26	0.31	324.60	10.20
22.00	1.07	933	35.45	6.58	0.34	294.13	11.18
24.00	1.19	844	38.17	6.90	0.37	267.75	12.11
26.00	1.30	769	40.82	7.21	0.41	244.77	13.00
28.00	1.42	705	43.39	7.53	0.45	224.63	13.83
30.00	1.54	649	45.89	7.85	0.48	206.88	14.62
32.00	1.66	601	48.32	8.16	0.52	191.15	15.37
34.00	1.79	558	50.69	8.48	0.56	177.14	16.08
36.00	1.92	521	52.99	8.79	0.61	164.63	16.76
38.00	2.05	487	55.24	9.11	0.65	153.39	17.40
40.00	2.19	457	57.42	9.43	0.70	143.27	18.00
42.00	2.33	430	59.55	9.74	0.75	134.11	18.58
44.00	2.47	405	61.63	10.06	0.79	125.81	19.13
46.00	2.61	383	63.66	10.38	0.85	118.25	19.65
48.00	2.76	363	65.63	10.69	0.90	111.36	20.15

307 N: tree density; QMD: quadratic mean diameter; TAR: tree area ratio; BA: basal area; CW: crown width;
308 MCA: maximum crown area.

309 The final stocking chart (Figure 5) integrates these predictions: the A-line
310 represents biological carrying capacity, the B-line represents the management
311 threshold, and relative density iso-lines (40–90 %) allow classification of stands as
312 understocked, fully stocked, or overstocked.



313

314 **Figure 5.** Stocking chart for *Pinus occidentalis* in La Sierra, Dominican Republic
315 shows a maximum size–density boundary (A-line) and a management threshold
316 (B-line) based on tree area ratio and crown–diameter allometry, respectively.

317 Tree density is on the x-axis, and basal area on the y-axis. These lines help
318 evaluate stand occupancy and inform silviculture practices.

319 The developed stocking guide (Figure 5) assists in assessing stand density and
320 guiding thinning strategies for *P. occidentalis* stands in the studied region. It shows
321 the relationship between N (trees·ha⁻¹) and basal area (m²·ha⁻¹), with overlaid lines
322 indicating QMD (cm) and relative density (% of maximum stand occupancy). Tree
323 density (N) ranges roughly from 50 to 2 050 trees·ha⁻¹, while stand basal area
324 varies from 0 to approximately 70 m²·ha⁻¹. The iso-lines represent QMD (cm),
325 linking different N and basal area combinations that lead to the same average tree
326 size. The diagonal lines labeled 40 % to 90 % show relative density or stocking
327 percent, representing the proportion of the maximum stand density (A-line).



328 The upper boundary of stand density (A-line) indicates the maximum number of
329 trees a species can support before density-related mortality occurs. For instance,
330 a *P. occidentalis* stand here, with 550 trees·ha⁻¹ and a basal area of 60 m²·ha⁻¹,
331 approaches this limit. The B-line marks a management threshold, often linked to
332 crown closure or the minimum efficient stocking rate. The diagonal lines (40–90
333 %) show stocking levels relative to maximum density. Stands near the 40–50 %
334 lines may be understocked, meaning site resources are not fully utilized. Those
335 between 60-80 % are usually fully stocked and efficiently using the site, allowing
336 growth without excessive competition. Stands close to the 90 % line are nearing
337 biological capacity, indicating the need for thinning to reduce competition. QMD
338 lines help estimate average tree size at different N and basal area levels,
339 connecting stand structure with density dynamics.

340 The development of the *P. occidentalis* stocking guide for La Sierra provides the
341 first quantitative framework for assessing stand occupancy and management
342 thresholds in Dominican pine forests. It establishes two key references: the A-line,
343 representing maximum stand density, and the B-line, defining the management
344 threshold based on crown allometry. This dual approach follows the Gingrich-style
345 and density-management diagram tradition applied in North America, Asia, and
346 Europe (Jang et al., 2021; Kara & Topaçoglu, 2018; Kondoh, 2023; Yang &
347 Brandeis, 2022), and parallels Mexico's long-standing use of stocking guides
348 across its highly diverse pine forests (Acevedo-Benítez et al., 2018; Cabrera-Pérez
349 et al., 2019; Romero-Sanchez et al., 2018; Vargas-Larreta et al., 2024).

350 The A-line of *P. occidentalis* traces a self-thinning trajectory from 1 817 trees·ha⁻¹
351 at 12 cm QMD to 363 trees·ha⁻¹ at 48 cm. At 32 cm QMD, predictions reach 601
352 trees·ha⁻¹ and 48.32 m²·ha⁻¹ (Table 3), aligning with values for *Pinus densiflora*
353 Siebold & Zucc. and *Larix kaempferi* (Lamb.) Carrière in Korea (Lee & Choi, 2020).
354 The basal area increased from 20.6 to 65.6 m²·ha⁻¹ across size classes,
355 underscoring high carrying capacity, comparable to *Pinus palustris* Mill. (Kara et
356 al., 2017), *Pinus sylvestris* L. (Kara, 2018), and *Pinus ponderosa* Douglas ex C.
357 Lawson (Jang et al., 2021). Dominican values often exceed temperate



358 benchmarks, likely reflecting species-specific growth dynamics and the favorable
359 climatic conditions of high-elevation Caribbean environments.

360 The B-line provides a biologically based threshold, ensuring sufficient growing
361 space, which parallels canopy closure concepts (Kondoh, 2023). Species-specific
362 crown allometry is critical: *Pinus brutia* Ten. shows earlier closure due to wider
363 crowns in open conditions (Kara & Topaçoglu, 2018). In *P. occidentalis*, the gap
364 between A- and B-lines defines understocked versus fully stocked conditions.
365 Relative density iso-lines (40-90 %) aid decision-making, similar to *P. sylvestris*
366 where B-line BA spans 11-29 m²·ha⁻¹ (Kara, 2018). At 32 cm QMD, the Dominican
367 B-line predicts 191 trees·ha⁻¹, notably lower than 313-370 trees·ha⁻¹ for Korean
368 species (Lee & Choi, 2020), again highlighting a unique crown structure.

369 Site-specific variation in maximum size-density relationship and thresholds is well
370 documented. For *Pinus rudis* Endl. in Mexico, A-lines relied on Reineke's model
371 (Martínez-Santiago et al., 2021), while *P. sylvestris* canopy closure thresholds vary
372 by site quality (Kara, 2018). The *P. occidentalis* guide fills a regional knowledge
373 gap, recommending a thinning density of between 40-70 % relative to the original
374 density. Flexibility in defining the management zone is essential, as it can shift
375 depending on goals and intensity (Ray et al., 2023).

376 Departures below the B-line suggest regeneration needs, while proximity to the A-
377 line indicates thinning to reduce mortality. This reflects best practice, where
378 stocking charts balance production, resilience, and ecosystem services (Jang et
379 al., 2021). Though robust A- and B-lines are now established (Table 3; Figure 3),
380 further refinements using growth and yield data, long-term thinning trials, and site
381 modifiers will strengthen predictive accuracy, following advances in density
382 modeling (Jang et al., 2021; Kara & Topaçoglu, 2018; Kondoh, 2023).

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Conclusions



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388 This study developed a species-specific stocking guide for *Pinus occidentalis* in La
389 Sierra, Dominican Republic, by integrating a maximum size–density boundary
390 derived from a tree area ratio model with a crown-based threshold derived from
391 crown–diameter allometry. Results supported hypothesis 1, showing that
392 maximum stand density follows a predictable size–density trend captured by
393 structural variables, with the tree area ratio model explaining about 90 % of the
394 upper-bound variation. Hypothesis 2 was further confirmed, since crown width
395 showed a significant increase with stem diameter, offering a biologically based
396 foundation for establishing minimum fully stocked conditions. The crown–diameter
397 link helped estimate the B-line, indicating the shift from underutilized to effective
398 canopy interaction. The A- and B-lines define a practical density management
399 window. Keeping stands at 40–70 % of maximum density encourages balanced
400 growth and efficient site use while reducing density-related mortality risk. This
401 framework offers a quantitative basis for adaptive density regulation in these pine
402 forests.

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Conflicts of Interest

405 The authors declare that we have no known financial conflicts of interest or
406 personal relationships that could have influenced the research presented in this
407 article.

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409

Declaration of the use of AI

410 The authors declare that no generative AI or AI-assisted technologies were used
411 in the conceptualization, analysis, or interpretation of this research. AI-based tools
412 were used solely for minor language editing and grammar correction.

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