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Original Article

Inventory-based assessment of tree growth variables for mixed tropical species in Okomu forest reserve, Nigeria

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A B S T R A C T

Forest inventory is a crucial component of sustainable forest management that requires strong monitoring programmes. However, due to the perceived high cost of forest inventory, many forest managers do not regularly update growth characteristics information. Updated information on growth variables is essential for determining forest production potential and ensuring accountability for sustainable management. This study investigated inventory-based assessment of tree growth variables for mixed tropical species in Okomu Forest Reserve (OFR), Nigeria. Using a systematic sampling technique, 2,949 trees with diameter at breast height (DBH) ≥ 10 cm were assessed within 60 plots measuring 50 m × 50 m, alternately laid at 200 m intervals along 15 transects (1 km each). Tree growth variables measured included DBH and total height (TH). Other variables estimated were Basal Area (BA), Stem Volume (SV), Stand Density (N), Canopy Cover, and Slenderness Coefficient (SC). Data were analysed using descriptive statistics. Results showed that DBH and TH ranged from 10–197 cm, 6.0–48.0 m respectively. BA ranged from 9.0–42.8 m^2/ha, SV (121.7–1094.0 m^3/ha), and N (128–424 trees/ha). Canopy cover was approximately 48%. About 35% of the trees were within the diameter class ≤ 20 cm; 0.2% and 0.6% were within the 100–110 cm and >110 cm classes, respectively. TSC showed that 68 trees/ha had high SC (>80), 28 trees/ha were moderate (TSC: 70-80) and 101 trees/ha (<70) were low. The study concludes that growth variables provide essential baseline information for effective forest management and decision-making and recommends consistent updating of tree growth data.

K E Y W O R D S : *Growth data, Inventory, Mixed tropical, Sustainable management, Variables*

INTRODUCTION

Forest can provide diverse tangible and intangible benefits and as a renewable asset, it could perpetuate its usefulness if properly managed. As a result, it requires quantifiable information for both management decision and sustainable management practices. Palmer and Synnott (1992) stated that sustainable management of forests can be attained by forest manager only if sufficient information about the forest stock is well documented. Programme and decision on sustainability should be based on full information of the natural resources, adequate research, monitoring and evaluation of natural resources.

Knowing tree growth characteristics and their importance would allow plans for proper silvicultural and other forest operations on the management of the forest estate (Chukwu *et al.,* 2020). To obtain the various information requirements for forest management, up-to-date inventory data on tree growth variables of a stand is essential. This is one of the means by which reliable data can be generated to guide management.

It keeps the forest managers informed on the growth pattern and changes on the forest stands. Sustainable management of forest stands can be safeguarded if current and consistent information on growth condition of the stands such as, trees growth attributes are available. Therefore, this study plans to provide

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baseline information that will enhance proper forest management decisions in Okomu Forest Reserve, Nigeria.

MATERIALS AND METHODS

The study area

This study was conducted in Okomu Forest Reserve (OFR), located in Edo State, Nigeria (6º 09' - 6º32' N; 5º1' - 5º27' E). The forest reserve (FR) has an estimated area of 1,120 km^2 and lies amid rivers Osse and Siluko to the east and west respectively. The vegetation of the OFR is distinctive Guinea–Congo lowland rainforest and is comprised of a mixture of swamp-forest, high forest, secondary forest, and open scrub (BirdLife International, 2011). The OFR comprises of semi-deciduous, moist, lowland rainforest and is archetypal of this fast-vanishing ecosystem of southwestern Nigeria. Freshwater swamp forests are found along the rivers. Okomu has a typical humid tropical climate characterized by two major seasons (rainy and dry). The rainy season lasts from March to October, while dry season lasts from November to February. December and January in Okomu are characterized by Harmattan. The mean annual rainfall of Okomu is 2100 mm with mean temperature of about 30ºC (Enaruvbe, 2018).

Data Collection

Sampling technique

The data for this study were collected from Okomu Forest Reserve, Nigeria. Systematic (line transect) sampling technique was adopted for plot demarcation, following Adekunle *et al.* (2004). To establish transects lines, Global Positioning Systems (GPS) receiver was used to determine the initial point of each transect (Husch *et al.,* 2003). In the selected locations, fifteen (15) transects of 1 km long situated 600 m apart were established. Four (4) sample plots of 50 m × 50 m (i.e. 0.25 ha) were alternately laid along each transect at 200 m intervals resulting to 60 plots for the 15 transects. Hence, sixty sample plots were used in this study. Diameters at Breast Height (DBH,cm), Crown diameter (CD,m) and Tree Total Height (H, m) of only living trees with D ≥ 10 cm within the selected sample plots were measured. Basal Area (BA, m^2), Stem Volume (SV, m^3), Stand Density (N), Canopy cover, and Slenderness Coefficient (SC) were estimated. Tree crown diameter was used in computing Canopy cover (CC); Canopy cover (CC) was used to calculate the percentage of area covered by live forest canopy.

Data Processing

Basal area (BA) computation and Volume estimation

$$BA = \frac{\pi D^2}{4} \qquad (1)$$

Where; BA = basal area (m^2), π = 3.142 (a constant), D = DBH (m)

Total stem volume was estimated using the Newton-Simpson's formula.

$$V = \pi \frac{H}{24}(D_b^2 + 4D_m^2 + D_t^2) \qquad (2)$$

Where; V = Total volume (m^3), H = Total height (m), π = Pi is constant (3.143)

D_b = Diameter at the base (cm); D_m = Diameter at mid-point (cm) and D_t = Diameter at the top (cm).

Tree Slenderness coefficient (SC)

$$SC = \frac{TH}{DBH} \qquad (3)$$

Where: SC = Tree slenderness coefficient, TH = Total height (m) and DBH = Diameter at breast height (m)

TSC classes: high (with SC > 80); moderate (with SC: 70-80) and low (with SC < 70) (Adeyemi and Adesoye, 2016).

Canopy cover: The percentage canopy cover was computed as follows:

$$C' = 100(\sum_{i=1}^{n} p_i CPA_i)A^{-1} \qquad (4)$$

To correct for crown overlap, equation 3.8 was used as suggested by Satterlund in Moeur, (1986).

$$C = 100\left[1 - exp^{(-0.01C')}\right] \qquad (5)$$

Where: C = percentage canopy cover that accounts for overlap, C'= percent canopy cover without accounting for overlap, CPA_i = crown projection area per ha for i^{th} tree, A = total area (m^2 per ha), P_i = plot area (m^2 per ha)

Data analysis

Complete exploratory data analysis: Descriptive statistics such as frequency, percentage, graph, mean; standard deviation, standard error, skewness and coefficient of variation (CV) were used to summarize the derived (computed) tree variables information.

RESULTS

The data sets used in this study were the inventory data of 2949 individual trees collected from Okomu Forest Reserve, Nigeria. The descriptive statistics of the data used in this study are shown in Table 1. Irrespective of the species measured, the distribution of stump diameter (Dst) ranged from 11.0 cm – 296.6 cm with the mean and standard error (SE) values of 33.1±0.39, DBH ranged from 10.0 cm – 197.0 cm with the mean and SE values of 29.4±0.36, TH ranged from 6.0 m – 48.0 m with the mean and SE values of 18.7±0.15, MH ranged from 2.0 m – 41.0 m with the mean and SE values of 13.5±0.13, crown diameter (CD) ranged from 1.2 m – 26.4 m with the mean and SE values of 5.3±0.05, BA ranges from 0.0079 m^2 – 3.2685 m^2 with the mean and SE values of 0.10±0.003 and Total stem volume (TSV) ranged from 0.0222 m^3 – 91.1585 m^3 with the mean and SE values of 2.02±0.10.

The results of stand growth variables are presented in Table 2. The mean and SE of the number of trees recorded was 197±60 trees/ha, with CV value of 0.27. The mean tree quadratic diameter and SE were 20.5±15.82 with CV value of 0.77. The mean and SE of BA and CPA were 19.4±6.67 m^2/ha and 5314.6±2336.00 m^2/ha with CV values of 0.34 and 0.44 respectively. The Mean and SE of Merchantable volume and Total stem volume of 295.9±142.67 m^3/ha and 397.3±189.92 m^3/ha with CV values of 0.48 and 0.48 respectively were recorded in the study area.

Table 1: Descriptive Statistics of the pooled data of the study area (N=2949)

Variable	Min.	Max.	Mean	Std.Error	Std. Dev	Skewness	Coef. of Variation
Dst (cm)	11	296.6	33.1	0.39	20.94	2.71	0.63
DBH (cm)	10	197.0	29.4	0.36	19.68	2.45	0.67
DM (cm)	3.5	160.0	23.9	0.33	17.80	2.55	0.74
DT (cm)	2.0	150.0	18.1	0.29	15.97	2.93	0.88
MH (m)	2.0	41.0	13.5	0.13	6.95	1.16	0.51
TH (m)	6.0	48.0	18.7	0.15	8.02	0.98	0.43
CL (m)	1.1	34.2	7.2	0.05	2.86	1.97	0.40
HCB (m)	1.0	39.0	11.5	0.13	6.89	1.16	0.60
CD (m)	1.2	26.4	5.3	0.05	2.45	2.21	0.46
CPA (m^2)	1.1	547.4	27.0	0.60	12.44	4.81	1.20
TSC	9.6	267.0	72.9	0.49	26.34	1.24	0.36
CR	0.07	0.89	0.4	0.003	0.14	0.44	0.34
BA (m^2)	0.0079	3.2685	0.1	0.003	0.19	7.25	1.90
M.Vol (m^3)	0.0138	81.25	1.5	0.08	4.12	8.61	2.70
TSV (m^3)	0.0222	91.159	2.0	0.10	5.18	7.76	2.56

Where: Dst= diameter at base, DBH= diameter at breast height, DM= diameter at middle, DT= diameter at top, TH= total height, MH merchantable height, HCB= height to live crown base, CD= crown diameter, CL= crown length, CR = crown Ratio, BA=Basal area, TSV = Total stem volume, M.Vol = Merchantable volume, CPA= crown projection area and TSC=Tree slenderness coefficient.

Table 2: Descriptive statistics for stand growth variables in the study area

	N/ha	QMDBH (cm)	CPA (m^2)/ha	BA (m^2)/ha	M.V (m^3)/ha	T.V (m^3)/ha
Mean	197	20.5	5314.6	19.4	295.9	397.3
SD	52.93	15.8	2335.10	6.67	142.67	189.92
CV	0.27	0.8	0.44	0.35	0.48	0.48

Where: SD= Standard deviation CV= coefficient of variation, N= Number of tree/ha, QMDBH= Quadratic mean diameter at breast height, BA=Basal area, T.V = Total stem volume, M.V = Merchantable volume and CPA= crown projection area.

The scatter plot of DBH and TH relationship (Figure 1) revealed a curve of monotony and upper asymptote with minimum and maximum growth rate. The scatter plot of DBH and MH is presented in Figure 2. The distributions of the number of trees per DBH class are presented in Figure 3. The diameter distributions curve exhibited an inverse J-shape which is distinctive of natural forest.

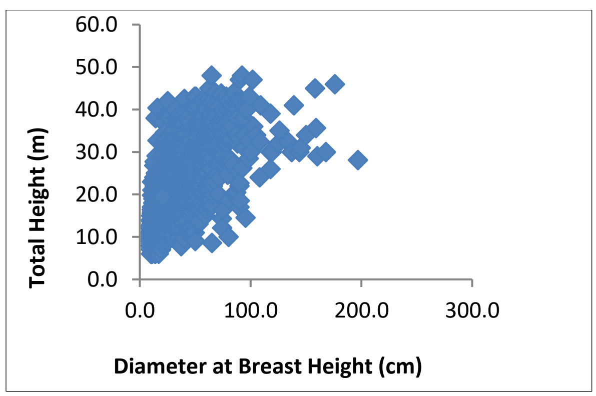

Figure 1: Relationship between Total Height and Diameter at breast height.

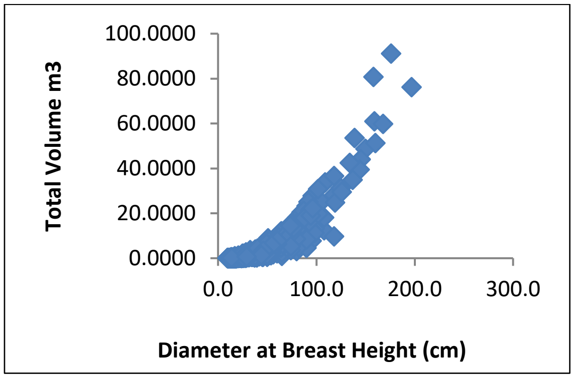

Figure 2: Relationship between Total stem volume and Diameter at breast height

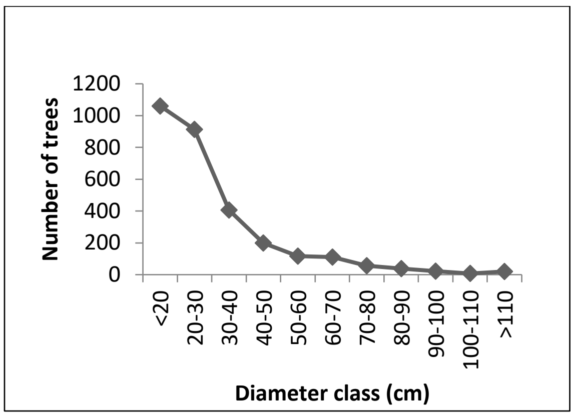

Figure 3: Diameter Class Distribution of trees in the study area

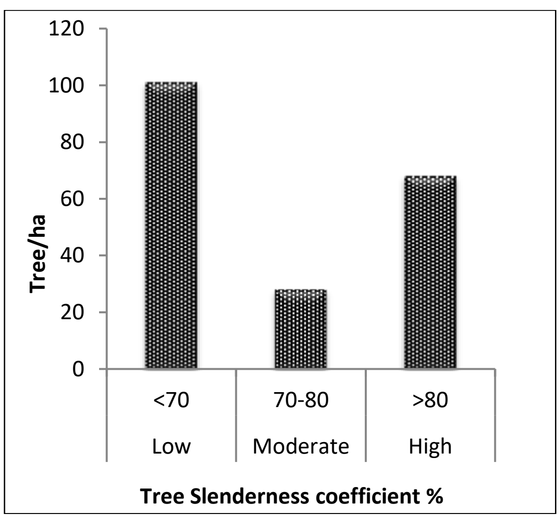

Figure 4: Tree slenderness coefficient for individual tree species

The frequency and percentage distribution of trees per DBH class are presented in Table 5. Thirty-five percent (1061 trees) of the trees encountered were in the diameter class of ≤ 20 cm. Only few trees amounting to 0.2% (7 trees) and 0.6% (19 trees) were in the diameter class of 100-110 and above 110 respectively. In addition, result of the categorization of tree slenderness coefficient (TSC) showed that 68 trees/ha had high slenderness coefficients (>80). About 28 trees/ha were moderately slender (TSC: 70-80) and 101 trees/ha had low slenderness coefficients (<70) (Figure 4). Similarly, the result of canopy cover and crown projection area per hectare of the study area as presented in Table 6, which revealed that mean crown projection area was 5314.62±2335.10 m^2/ha and CV value of 0.44 with about 48.34% canopy cover per hectare.

Table 5: Distribution of the various diameter class sizes

Diameter Class (cm)	Frequency	Percentage (%)
<20	1061	36.0
20-30	913	31.0
30-40	406	13.8
40-50	200	6.8
50-60	116	3.9
60-70	111	3.8
70-80	56	1.9
80-90	38	1.3
90-100	22	0.7
100-110	7	0.2
>110	19	0.6

Table 6: Canopy cover and crown projection area per hectare

	N/ha	CPA (m^2/ha)	% canopy cover
Mean	197	5314.62	48.34
Standard deviation	52.93	2335.10	
Coefficient of variation	0.27	0.44	

Where: N= Number of tree/ha and CPA= crown projection area.

DISCUSSION

The average number of trees per hectare in the study area is higher than those reported by Adekunle *et al.* (2004) for Ala (116 stems/ha) and Omo (96 stems/ha) forest reserves. The mean value was nevertheless lower than 508 trees per hectare reported by Onyekwelu *et al.* (2008) for three natural tropical forests ecosystems in Southwestern Nigeria. This may be due to the fact that tree density in Okomu forest reserve could be pretentious by natural disasters, human actions and edaphic factors. The basal area per hectare value recorded in this study was higher than that of Omo Forest Reserve (12.48 m^2/ha) as reported by Adekunle *et al.* (2004) and 15 m^2/ha for a well-stocked tropical rainforest recommended by Alder and

Abayomi (1994). Despite that, it is lower than that of Shasha (23.42 m^2/ha) and Ala (22.98 m^2/ha) Forest Reserves as report by Adekunle *et al.* (2004). This may be as a result of immense stress on the forest equated to whatever was obtained in various tropical forests of the world with more conservation efforts. The average merchantable and total stem volumes per hectare documented are higher compared to the values reported in some of the previous researches for tropical rainforest ecosystems in Nigeria such as Adekunle *et al.* (2004), Adekunle and Olagoke (2008).

The results of the proportion of the trees encountered disclosed that highest number of trees was in the diameter class of ≤ 20 cm. Equally, Oduwaiye and Ajibode (2005) recounted diameter class of 11-30 cm at Onigambari Forest Reserve, Ibadan, Nigeria having the uppermost number of trees. Fewer trees were in the diameter class of 100-110 and above 110. This implies that the forest needs to be left for more years before harvesting. This is related to the findings of Ihenyen et *al.* (2009) at Ehor Forest Reserve, in Nigeria. Additionally, the diameter distributions curve obtained in this study exhibited an inverse J-shape which is an indication of a healthy recruitment of the individuals in the study area.

According to Nath e*t al.* (2005), the reversed J–curve, wherever the abundance decreases with growing diameter, showed a sign of good restoration of the component species. This is in line with the report of Onyekwelu *et al.* (2021) who revealed that DBH distribution curves in their study of understory species diversity, regeneration and recruitment potential of sacred grooves in south western, Nigeria showed highest stand density at the lowest class (10–20 cm) and decreased with increasing DBH, indicating good regeneration status and healthy ecosystem. This conforms to the populace structure of trees in the study area. Similarly, as the diameter increased, there was a decrease in the number of stems. This substantiates the results of Adekunle *et al*. (2013).

The result of the categorisation of TSC revealed that 101 trees/ha in the study area have low slenderness coefficient which means low susceptibility to wind throw and excellent stability according the previous studies of Slodicak and Novak (2004) and Kontogianni *et al*. (2011). However, 68 trees/ha in the study area have high slenderness coefficient (TSC>80) which indicates high risk of being damaged by wind-throw. Rudnicki *et al.* (2004) reported that slenderness coefficient values of trees above a verge of 80 are susceptible to wind heave and injuries. The finding of this study may be due to lack of appropriate silvicultural treatments and competition. Tree competition for light and space results in high slenderness thereby increasing the risk of stem damage through bending stress. According to Jullien *et al.* (2013), high tree slenderness coefficient is an accurate predictor of tree growth rate.

The percentage canopy cover of the forest reserve in this study was about 48% which implies that in a hectare (10,000 m^2), about 0.48ha (4800 m^2) of the land area were under canopy cover while about 0.52 ha (5200 m^2) of land area were not under canopy cover. The percentage cover exhibited in the study area might be due to anthropogenic undertakings and illegal logging despite the conservation measures. According to Franklin *et al.* (2007), disruption creates great adverse effects on the forest canopy structure, which in turn affects the general productivity of the forest per unit area.

CONCLUSION AND RECOMMENDATIONS

This study has shown that Okomu Forest Reserve is better stocked than most of other tropical rainforests in Nigeria especially those of the southern part of the country Nigeria. The mean number of trees and basal area per hectare obtained in the study area were higher than the values reported for other tropical rainforests of Nigeria. This study therefore recommends, that inventory of forest estate should be regularly conducted and documented at least every five years when reasonable growth changes must have occurred in order to provide up-to-date information on the stocking of the forest for proper management.

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Authors' Contributions
JUE managed the conceptualization, data curation, formal analysis, funding, methodology, project administration, validation, visualization and writing original draft and approved the final manuscript.

Ethical Statement
Not applicable.

REFERENCE

Adekunle, V.A. J., Olagoke, A. O and Akindele, S.O. 2013. Tree species diversity and structure of a Nigerian strict nature reserve. *International Society for Tropical Ecology* 54.3: 275 – 289.

Adekunle, V.A.J and Olagoke A.O. 2008. Diversity and biovolume of tree species in natural forest ecosystem in the bitumen-producing area of Ondo State, Nigeria: A baseline study *Bio-diversity and Conservation* 17: 2735 – 2755.

Adekunle, V.A.J., Akindele S.O. and Fuwape J.A. 2004. Structure and yield models of tropical lowland rainforest ecosystem of southwest Nigeria. *Food, Agriculture and Environment* 2.2: 395 – 399.

Adeyemi, A. A and Adesoye, P.O. 2016. Tree Slenderness Coefficient and Percent Canopy Cover in Oban Group Forest. *NigeriaJournal of Natural Sciences Research*www.iiste.org ISSN 2224-3186 (Paper) ISSN, 2225-0921 (Online): 6.4: 31 – 42.

Alder, D. and Abayomi, J.O. 1994. Assessment of data requirements for sustained yield calculations, unpublished report prepared for the Nigeria Tropical Action Programme, FORMECU, Federal Department of Forestry, Ibadan, Nigeria 28.

Birdlife International. 2011. Global IBA Criteria, viewed 27 June 2011, <http://www.birdlife.org/datazone/info/ibacritglob.

Enaruvbe, G.O. 2018. A systematic assessment of plantation expansion in Okomu Forest Reserve, Edo State, Southern Nigeria. *Nigerian Research Journal of Engineering and Environmental Sciences* 3.1: 39 – 47.

Chukwu, O., Ezenwenyi, J.U and Emebo, A.A. (2020). Growth variables assessment for young *Tectona grandis* Linn. f. plantation in Nnamdi Azikiwe University Awka, Southeastern Nigeria. *Research Journal of Agriculture and Forestry Sciences.* 8(4): 1-8.

Franklin, J.F., Mitchell, R.J. and Palik, B.J. 2007. Natural Disturbance and Stand Development Principles for Ecological Forestry. USDA Forest Service, Northern Research Station, General Technical Report NRS 19: 48.

Husch, B., Charles, I. M and Thomas, W. B. 2003. *Forest Mensuration*. The Ronald Press Company, New York, U. S. A 120 – 123.

Ihenyen, J., Okoegwale, E. E. and Mensah, J. K. 2009. Composition of Tree Species in Ehor Forest Reserve, Edo State, Nigeria. *Nature and Science* 7.8:8 – 18.

Jullien, D., Widmann, R., Loup, C. and Thibaut, B. 2013. Relationship between tree morphology and growth stress in mature European beech stands. *Annals of Forest Science* 684: 681 – 688.

Kontogiannia, A., Tsitsonia, T. and Goudelis, G. 2011. An index based on silvicultural knowledge for tree stability assessment and improved ecological function in urban ecosystems. *Ecological Engineering* 37: 914 – 919.

Nath, P.C., Arunchalam, A., Khan, M.L., Arunchalam, K. and Bharbhuiya, A.R. 2005. Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, Northeast India. *Biodiversity and Conservation* 14: 2109 – 2136.

Oduwaiye, E.A and Ajibode, M.O. 2005. Composition of Tree Species and Regeneration Potentials at Onigambari Forest Reserve, Ibadan, Oyo State, Nigeria. *Journal of Raw Materials Research* 2.1: 4 – 13.

Onyekwelu, J.C., Lawal, A., Mosandl, R., Stimm, B. and Agbelade, A.D. 2021. Understory species diversity, regeneration and recruitment potential of sacred groves in south west Nigeria. *Tropical Ecology* https://doi.org/10.1007/s42965-021-00157-2

Onyekwelu, J.C., Mosandl, R. and Stimm, B. 2008. Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in South-Western Nigeria. *Journal of Tropical Forest Science* 20.3: 193 – 204.

Palmer, J. and Synnott. T. J. 1992. The Management of Natural Forests. *In*: Sharma, N.P. (Editor) *Managing the World's Forests*, Kendall/ Hunt Publishing Co, Dubuque, Iowa 337 – 373.

Rudnicki, M.R., Mitchell, S.J. and Novak, M.D. 2004. Wind tunnel measurements of crown streamlining and drag relationships for three conifer species. *Canadian Journal of Forest Research* 34: 666 – 676.

Slodicak, M. and Novak, J. 2006. Silvicultural measures to increase the mechanical stability of pure secondary Norway spruce stands before conversion. *Forest Ecology and Management* 224: 252 – 257.