SITE INDEX EQUATIONS FOR *PINUS KESIYA* IN CAMEROON

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FONWEBAN, J. N., TCHANOU, Z. & DEFO, M. 1995. Site index equations for *Pinus kesiya* in Cameroon. This paper describes the development of a site index equation for *Pinus kesiya* in West Cameroon. Data were collected from 109 temporary circular plots in *Pinus kesiya* stands aged between 5 and 34 years. Amongst the models tested, the Chapman-Richards function provided the best results in terms of fit and general behaviour. This function was used to generate anamorphic site index curves for the species. The results will serve as a basis for site classification and in the development of a growth and yield prediction model for the species.

Key words: Site quality - site index - growth and yield - *Pinus kesiya* - Cameroon

FONWEBAN, J. N., TCHANOU, Z. & DEFO, M. 1995. Persamaan-persamaan indeks tapak untuk *Pinus kesiya* di Cameroon. Kertas kerja ini menerangkan pembangunan satu persamaan indeks tapak untuk *Pinus kesiya* di Cameroon Barat. Data dikumpul dari 109 plot-plot bulat sementara pada dirian *Pinus kesiya* yang berumur antara 5 dan 34 tahun. Antara model-model yang diuji, fungsi Chapman-Richards memberikan keputusan terbaik dari segi kesesuaian dan kelakuan. Fungsi ini digunakan untuk menghasilkan lengkungan indeks tapak anamorfik untuk spesies ini. Keputusan ini akan digunakan sebagai asas untuk klasifikasi tapak dan dalam pembangunan model ramalan pertumbuhan dan hasil untuk spesies ini.

Introduction

Several authors have expressed the need for site quality evaluation. Site quality determination serves as a guide in the classification of forests into productive classes (Lundgren 1980, Pandey 1987), as a means for rational land use planning (Hocker 1979), for judicious forest management or for growth and yield predictions (Spurr 1952, Spurr & Barnes 1980), as a useful guide in species selection for plantation forestry (Spurr & Barnes 1980), and even as a basis for economic analysis and investment justifications for some plantation projects (Carmean 1975, Clutter *et al.* 1983, FAO 1988).

Of the site quality measures assessed so far, site index is probably the most direct and most widely used in forestry (Aust & Hodges 1988, Clutter *et al.* 1983) and is probably the most efficient, best or most objective tool for evaluating forest site productivity (Trousdell *et al.* 1974, Lundgren 1980).

Pinus kesiya was introduced in the Melap Forest Reserve in Cameroon around 1953. Seeds came from South Africa and Madagascar (Tchanou 1990), the seed sources of which were the Phillipines and Vietnam respectively (Armitage & Burley 1980). It is now the most widely planted exotic pine covering about 65% of the pine acreage of the reserve. It is also the main species planted in the Koutaba Forest Reserve and has been tried in other forest reserves.

Studies have shown that *Pinus kesiya* in Melap has good strength properties to be used as electric and telephone poles (Bengono 1986, Yepmo 1985) and that when sawn it can provide good quality timber. Presently, the National Electricity Corporation (SONEL) relies on *Eucalyptus saligna* for transmission poles in Cameroon. There is a further demand for poles by neighbouring countries like Nigeria and Chad. A forest exploitation company at Massangam, 70 km from the reserve, is willing to saw *Pinus kesiya* wood and a paper pulp industry (Cellucam probably to be restarted) may be interested in the pine wood for pulp. It is clear that there will be an increasing demand for both pine and eucalyptus products by the forest-based industries.

Because of the economic returns from these species, the Tropical Forestry Action Plan for Cameroon (FAO 1988) advocated the expansion of its plantation programme to include the northern arid regions of Cameroon, the planting of about 1000 ha per year with these species and the creation of a sawmill near the plantation site. However, for this programme to be successful and for the species to provide the demanded products in a sustained manner, efficient management of the plantations is needed. Efficient forest management requires information on the productive potentials of the land on which the species are planted. It is a critical step to intensive forest management for the species concerned (Carmean 1975). The development of site index equations can serve this purpose. In Cameroon as elsewhere in Africa, little attention has been given to site index development for the planted species.

The purpose of this study was to develop anamorphic site index curves for unthinned stands of *Pinus kesiya* in the Melap Forest Reserve, West Cameroon. The results will serve as a basis for the development of a growth and yield prediction system for the species and will also provide a basis for comparison of its growth performance with results registered in other areas.

Materials and methods

Study site

Data for this study were collected at the Melap Forest Reserve (between 5° 44' and 5° 48' N, and 10° 52' and 10° 54' E.). Elevations range from 1000 to 1200 m and slopes vary between 0 and 80 %. The former vegetation was a wooded savanna with a grass understory. Melap experiences a rainy season of about eight months (March to October), with an annual rainfall of about 1649 mm and a mean annual temperature of 22.4 °C. Two soil types have been identified (Segalen, 1960): the less evolved soils (lithosols and alluvial soils) and ferrallitic soils (with or without concretions). The latter soils cover most of the reserve, and on these the pines are planted.

Data collection

A total of 109 temporary circular plots of 100 m^2 were established in 17 pure even-aged stands of *Pinus kesiya* in such a way that the whole range of sites could be represented. Measurements made on each plot with the Suunto Clinometer included the total height of four to six dominant and codominant trees and the steepest slope of the plot. Plot age was noted based on plantation records. Observations were also made on the nature of the soil (presence or absence of concretions). Stands showing evidence of excessive damage or human intervention were excluded from the dataset. Plot slopes varied between 2 and 23% and stand age ranged between 5 and 34 years. A detailed description of the dataset is found in DEFO (1991).

Data analysis and model development

A growth model was sought that would describe dominant height growth for *Pinus kesiya* at Melap. Based on a review by Armitage and Burley (1980), only sketchy information exists on the yield of this species. Armitage and Burley (1980) present a few models describing dominant height growth for kesiya pine, developed by Revilla *et al.* (1976) for natural stands in the Philippines and by Kingston (1972) for plantation stands in Uganda. One of the most complete works on the growth and yield of *Pinus kesiya* is perhaps that by Saramki (1992) in Zambia.

For this study, the following mathematical growth models were tested :

$H0 = K\exp(-\beta 1/\text{Age})$	Schumacher model
$H0 = K[1 - \exp(-\beta 1 * \text{Age})]\beta 2$	Chapman-Richards Model
$H0 = K(1-\exp(-\beta 1 * \text{Age}\beta 2))$	Modified Weibull model
$H0 = K[1 - \beta 1 \exp(-\beta 1 * \text{Age})]$	Mitscherlich model
$H0 = K\exp(-\beta 1/(\text{Age})\beta 2)$	Korf-Lindqvist model (pers. comm.).

where $H0$ = height of dominant and codominant trees (m),
$K, \beta 1, \beta 2$ = regression coefficients to be estimated.

These functions were fitted using non-linear regression methods (SAS 1987). The guide curve method for site index curve development described in Alder (1980), Avery and Burkhart (1983), and Clutter *et. al.* (1983) was used. The models were evaluated using the mean square error (MSE) and the sum of square errors (SSE) as well as graphical displays to observe the growth trends. The best model obtained was used to generate site index curves for *Pinus kesiya.*

Results

Model fitting

Results for the models fitted are shown in Table 1.

Table 1. Results for the fitted growth functions to *Pinus kesiya* dataset

Model	df	SSR	MSEK	$K \pm \sigma k$	$\beta 1 \pm \sigma\beta 1$	$\beta 2 \pm \sigma\beta 2$
SCH*	107	541.5485	5.0612	49.2640 ± 1.0845	12.1601 ± 0.3530	
CR	106	418.3620	3.9468	43.4523 ± 3.4870	0.0463 ± 0.0060	1.1947 ± 0.0792
Mit.	106	413.1984	3.8981	48.4855 ± 3.2020	1.0610 ± 0.0275	0.0411 ± 0.0054
KORF.	106	410.5901	3.8735	117.1978 ± 37.4302	6.1218 ± 0.3681	0.4661 ± 0.0901

* SCH = Schumacher model, CR = Chapman-Richards, Mit. = Mitscherlich, KORF. = Korf-Lindqvist, $\sigma\beta$ = standard error of estimate for the parameter.

From the table, it can be seen that the Korf-Lindqvist, Mitscherlich and Chapman-Richards models seem to fit better to the pine dataset than the Schumacher model. This is evidenced by the lower SSE and MSE. The Korf-Lindqvist model is just a variation of the Schumacher model with an additional parameter. Its better performance compared to the Schumacher model is therefore understandable.The Korf-Lindqvist and the Mitscherlich models have a slightly lower residual values indicating probably better fits than the Chapman-Richards model. Graphical displays of their growth trends did not show any apparent differences between the Mitscherlich and the Korf-Lindqvist models, but the Chapman-Richards model presented a curve lower than for the others, and also underestimated dominant (top) height (cf. figures in appendix). The choice therefore had to be made between the Mitscherlich and Korf-Lindqvist models. The fact that the Mitscherlich model has no point of inflexion led us to use the Korf-Lindqvist model in preference. The model was thus used to generate site index curves for *Pinus kesiya.*

Site index curves

The equation for the guide curve is

$$H0 = 117.1978\exp[-6.1218/(\text{Age})^{0.4661}] \qquad [1]$$

Using an index or base age of 25, the calculated top height is 29.9 m. Hence, the guide curve is the curve with a site index of 29.9 m (≈ 30 m). To get curves for other site index values, the shape parameters $\beta 1$ and $\beta 2$ were held constant and the asymptote parameter K was varied so as to achieve the required $H0$ value when age equals $A0$ (the index age) (Clutter *et. al.* 1983). The equation of the curve for site index S is thus:

$$S = K^*\exp[-6.1218/(A0)^{0.4661}] \quad [2]$$

so that $$K = S/\exp[-6.1218/(A0)^{0.4661}] \quad [3]$$
$$= S/0.2552469 \text{ or } S^*3.91777 \text{ (when } A0 = 25)$$

substituting [3] in [1] gives

$$H0 = 3.91777^*S^*\exp[-6.1218/(Age)^{0.4661}] \quad [4]$$

Equation [4] defines a family of anamorphic height/age or site index curves for given values of S. In order to predict or estimate site index for a stand with given average height of dominant and codominant trees and age, equation [4] can be algebraically rearranged giving

$$S = H0/3.91777\exp[-6.1218/(Age)^{0.4661}] \quad [5]$$

The classification of the plots into the various site classes was done using equation [5]. This resulted in five site classes : I (38 m), II (34 m), III (30 m), IV (26 m) and V (22 m), arranged in decreasing order of productivity. Thus Site I is the most productive while Site V is the poorest. About 94 % (102) of the plots fell within site classes II to IV, with the average site being II with 44 % of the plots. These values for site index were substituted in equation [4] to generate a family of site index curves (Figure 1).

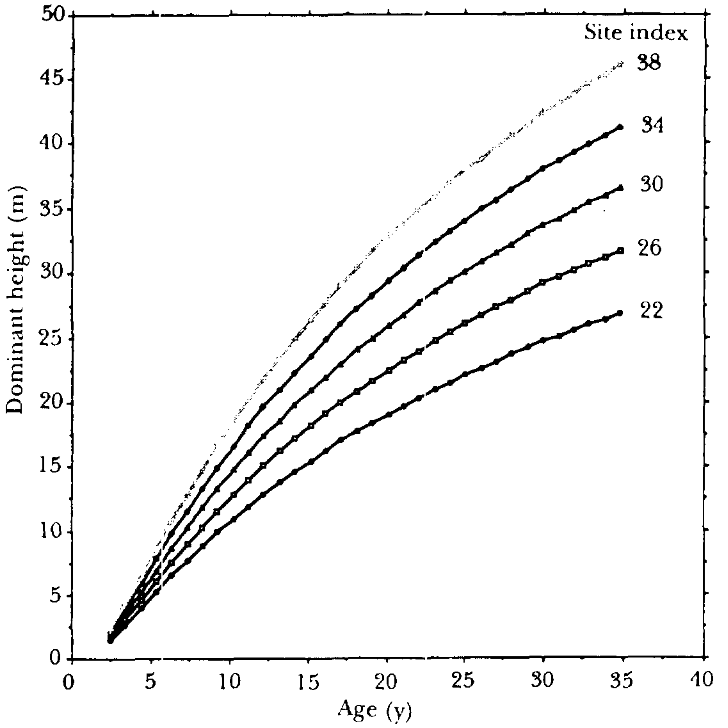

Figure 1. Site index curves for *Pinus kesiya* in Cameroon

Site classification

Analysis of variance indicated that tree growth was better on ferralitic soils without concretions than on soils with concretions. Topographic position was also significant: in general, plots located on hill tops had poorer site quality than those on valleys. Plots on gentle slopes had better site quality than those on steep slopes. These results agree with those obtained from similar studies in temperate regions (e.g. Carmean 1975, Hocker 1979).

Discussion

It would have been worthwhile comparing the results obtained in this study with those from other studies. However, the comparison seems to be difficult because most of the results were either based on mean tree heights or were very sketchy (cf. Armitage & Burley 1980). Results obtained for natural stands in the Philippines indicate that *Pinus kesiya* can grow to a dominant height of 23.5 m in 25 years, a value far lower than the one obtained for the Melap forest (24.5 m at 17 years, 28.8 m at 23 years and 29.3 years at 26 years). This is an indication that this species can perform better under plantation conditions than in natural stands. The better performance of species in plantations may not be very strange because of the better maintenance it is provided under such conditions. Aguire-Bravo and Smith (1986) found that *Pinus patula* grows better in plantations in South Africa, Kenya, Malawi and Zimbabwe than in their native forests in Mexico. The results in Melap are, however, comparable with those obtained in plantations in Zambia (29.7 m at 25.5 years with Philippine seed source) and those from Uganda. Saramki (1992) found site index differences between seed sources from Vietnam, Philippines and Malagasy.

Application

The site index curves obtained can be used to determine the site quality of a stand of *Pinus kesiya* given its age and an estimate of its dominant height. Let us consider, for example, a 15-year-old pine stand at the Melap forest with average dominant height estimated at 23.5 m. Using equation [5] we get an estimate of 33.9 m ($\approx$ 34 m) for its site index. This is quite close to the 34 m curve, so we can suppose that this stand will follow the growth trend as depicted by this curve. Another stand of the same age whose dominant height is 15.6 m will have a site index of 22.5 m and will be placed in the 22 m curve. In this way, we can classify a series of stands into various site quality classes.

The fact that dominant height is not greatly affected by silvicultural practices (thinning, etc.) and that it is closely related to stand yield ('Eichhorn's law) makes it a very useful index in growth and yield predictions. The site index equations obtained in this study should serve as basis for future development of a growth and yield model for *Pinus kesiya* in Cameroon.

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Appendix

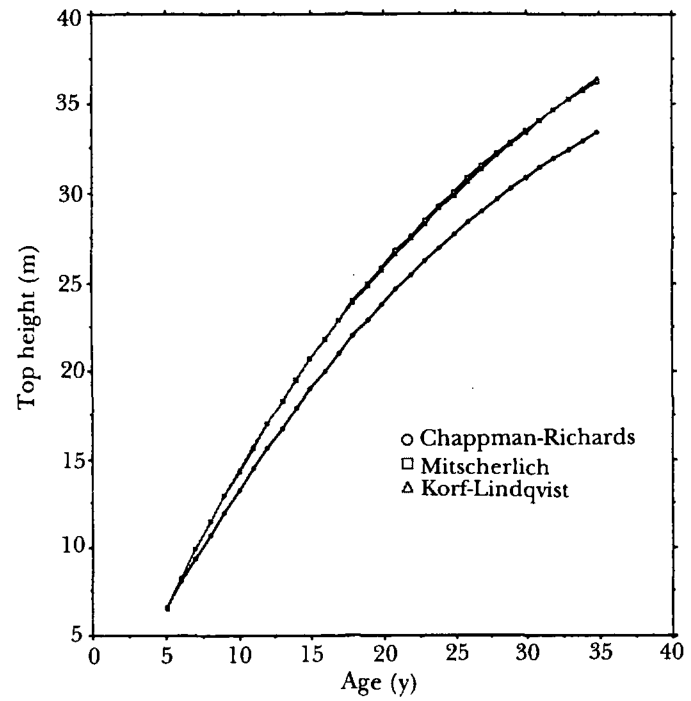

Figure (i). Top height growth trends for *Pinus kesiya* as depicted by the Chapman-Richards, the Mitscherlich and the Korf-Lindqvist functions

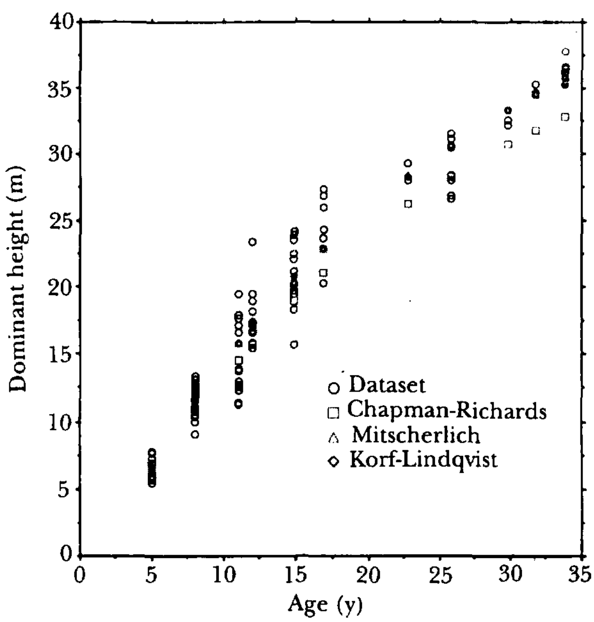

Figure (ii). Top height growth trends for *Pinus kesiya* as depicted by the Chapman-Richards, the Mitscherlich and the Korf-Lindqvist functions with datapoints included

Table (i). Data used for site index curves in Figure 1

Age (y)	S22	S26	S30	S34	S38
2	1.025 191 65	1.211 590 13	1.397 988 62	1.584 387 1	1.770 785 58
3	2.199 058 23	2.598 887	2.998 715 77	3.398 544 54	3.798 373 31
4	3.484 708 86	4.118 292 29	4.751 875 72	5.385 459 15	6.019 042 58
5	4.784 074 31	5.653 906 01	6.523 737 7	7.393 569 4	8.263 401 09
6	6.054 749 09	7.155 612 57	8.256 476 04	9.357 339 51	10.458 203
7	7.278 771 08	8.602 184 01	9.925 596 93	11.249 009 9	12.572 422 8
8	8.449 462 67	9.985 728 6	11.521 994 5	13.058 260 5	14.594 526 4
9	9.565 533 65	11.304 721 6	13.043 909 5	14.783 097 5	16.522 285 4
10	10.628 282 2	12.560 697 1	14.493 112 1	16.425 527	18.357 942
11	11.640 207	13.756 608 2	15.873 009 5	17.989 410 8	20.105 812
12	12.604 299 1	14.895 989 9	17.187 680 7	19.479 371 4	21.771 062 2
13	13.523 676 8	15.982 527 1	18.441 377 5	20.900 227 8	23.359 078 1
14	14.401 397 6	17.019 833 5	19.638 269 4	22.256 705 4	24.875 141 3
15	15.240 366 8	18.011 342 6	20.782 318 3	23.553 294 1	26.324 269 9
16	16.043 296 6	18.960 259 7	21.877 222 7	24.794 185 7	27.711 148 8
17	16.812 693 9	19.869 547 3	22.926 400 7	25.983 254 2	29.040 107 6
18	17.550 861 8	20.741 927 6	23.932 993 3	27.124 059 1	30.315 124 9
19	18.259 910 2	21.579 893 9	24.899 877 6	28.219 861 3	31.539 845
20	18.941 769 2	22.385 727 2	25.829 685 2	29.273 643 2	32.717 601 3
21	19.598 203 1	23.161 512 8	26.724 822 4	30.288 132 1	33.851 441 7
22	20.230 826 1	23.909 158 1	27.587 490 2	31.265 822 2	35.944 154 2
23	20.841 115 7	24.630 409 5	28.419 703 3	32.208 997 1	35.998 290 8
24	21.430 426 1	25.326 867 2	29.223 308 4	33.119 749 5	37.016 190 6
25	22.000 000	26.000 000	30.000 000	34.000 000	38.000 000
26	22.550 979 5	26.651 157 6	30.751 335 7	34.851 513 8	38.951 691 9
27	23.084 415 9	27.281 582 5	31.478 749	35.675 915 5	39.873 082 1
28	23.601 278 6	27.892 420 2	32.183 561 8	36.474 703 3	40.765 844 9
29	24.102 462 7	28.484 728 6	32.866 994 5	37.249 260 5	41.631 526 4
30	24.588 795 9	29.059 486	33.530 176 2	38.000 866 4	42.471 556 5
31	25.061 045 2	29.617 598 9	34.174 152 6	38.730 706 2	43.287 259 9
32	25.519 922 2	30.159 908 1	34.799 893 9	39.439 879 8	44.079 865 7
33	25.966 088 1	30.687 195	35.408 302	40.129 408 9	44.850 515 8
34	26.400 158 2	31.200 187	36.000 215 7	40.800 244 5	45.600 273 3
35	26.822 705 9	31.699 561 5	36.576 417 2	41.453 272 8	46.330 128 4