Additive Basal Area in Knysna Forest – Myth or Reality ?

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ABSTRACT

This paper explores the additive basal area phenomenon wherein the basal area of large above-canopy trees in a plot appears additive or extra to the total basal area of the plot. The mean basal area of *Podocarpus falcatus* and *Podocarpus latifolius* in 0.04 ha plots were studied in 2032 plots at eleven sites in the Knysna forest, in relation to the basal area of the remaining species and the total basal area. Mean basal area regressions indicated that the basal area of *P. falcatus* and *P. latifolius* were 'additive'. The basal area of plots with big trees and those without were compared and significant differences provided further support for this 'additive basal area' theory.

INTRODUCTION

Paijmans (1970) found that in New Guinea forest, plots with the tall emergent *Araucaria hunsteinii,* individually had a basal area much higher than the basal area of plots with non-emergent canopy. In other words the *Araucarias* gave the impression of being an additional basal area and did not appear to depress the basal area of the rest of the forest matrix.

Enright & Hill (1995) describe different models of total stand biomass behaviour. In one model the overall stand basal area remains fairly constant having reached a relatively stable maximum or carrying capacity. If the biomass of this stand has reached a carrying capacity then an increase in the basal area of one species in the stand should be offset by a decrease in the basal area of other species (Figure 1a). For example, if the basal area of the *Podocarpus* species increases, the basal area of the remaining forest species decreases, while the carrying capacity remains constant. This indicates competition between the *Podocarpus* species and the other species.

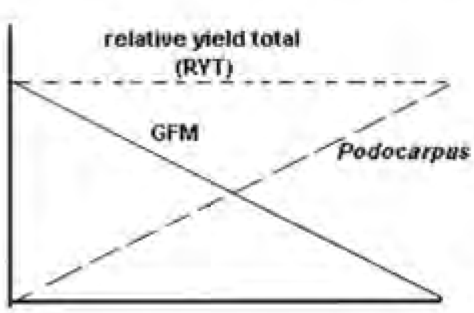


Figure 1a. A positive slope for a selected tree species e.g. *Podocarpus* is matched by a negative slope for the rest of the forest species (GFM, the general forest matrix) and the slope for the total basal area is zero (Enright & Hill, 1985).

In contrast to this, Enright's (1982) unusual 'additive basal area' hypothesis predicts that the relative yield total (RYT) increases as the *Podocarpus* biomass increases and the growth of the general forest matrix does not seem to be in competition with but is 'additive' to the *Podocarpus* species (Figure 1b). The carrying capacity of these stands is not constant and is dependent on the abundance of the *Podocarpus* (key) species (Enright & Hill, 1995).

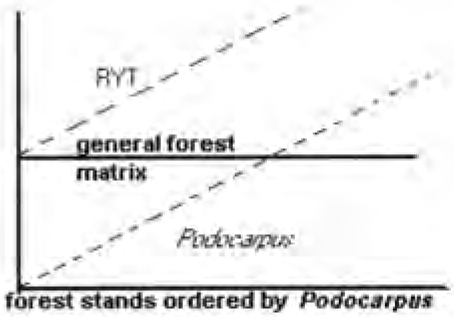


Figure 1b. Relative yield total increases as the biomass of *Podocarpus* increases. Growth of the general forest matrix does not appear to be affected by the presence of the *Podocarpus* (key) species i.e. the *Podocarpus* species is not competing with the other species (Enright & Hill, 1985).

Evidence to support this hypothesis comes from two conifers, *Araucaria hunsteinii* (Enright,1982) and *Agathis australis* (Ogden,1985). Enright (1982) tested the 'additive basal area' idea in New Guinea rainforest using density and basal area data for *Araucaria hunsteinii* and *Araucaria cunninghamii* D. Don. He found that regardless of the basal area of *Araucaria hunsteinii* in sampled stands in New Guinea, the basal area of the rest of the forest remained fairly constant. Stands that contained *Araucaria hunsteinii* could support more than double than those of the adjacent angiosperm stand but this was not the case for *Araucaria cunninghamii* however. Similarly Ogden (1985) found that this 'additive basal area' phenomenon also occurred in *Agathis australis* (kauri). "A high basal area of kauri does not depress its associates, nor a low value allow them to expand" (Ogden,1985).

Two southern hemisphere long-lived pioneer conifers *Podocarpus falcatus* (Thunb.) and *Podocarpus latifolius* (Thunb.) were selected to test this 'additive basal area' hypothesis in the Southern African context. *Podocarpus latifolius* (real yellowwood or broad-leafed yellowwood) and *Podocarpus falcatus* (Outeniqua yellowwood or common yellowwood) (=*Afrocarpus falcatus*, de Laubenfels,1985) are the most prominent members of the Knysna forest flora with *Podocarpus falcatus* being one of the most successful and tallest indigenous trees. *Podocarpus falcatus* produce the monarchs, living for 600 – 1000 years, reaching up to 60m in height and outliving and outgrowing all other species (von Breitenbach,1971). They have widely spreading crowns usually towering above the canopy. *Podocarpus latifolius* reaches heights of 25-30m and has a long, straight and often fluted trunk with a comparatively small crown (von Breitenbach, 1974).

The Knysna forest is the largest continuous forest in South Africa on the Southern coast of the Western Cape, covering an area of 568 km^2 (Midgley et al,1995). Knysna is an Afromontane type forest and is protected by the bow of the Outeniqua-Tsitsikama mountains. These coastal mountains create a barrier effect and permit the survival of this predominantly evergreen forest (von Breitenbach, 1974). The canopy height of the Knysna Forest ranges from 15-30m with a mean of 20m (Midgley et al,1995).

Enright (1982) partially attributed the hypothesis that *Araucaria hunsteinii* does not apparently compete for resources with the other rainforest tree species, to the morphological characteristics of this tree. "*Araucaria hunsteinii* is a sparsely branched emergent. No branching occurs below or within the main 'angiosperm' canopy layer and the sparse nature of the foliage interferes little with the passage of light to the broadleaf canopy" (Enright,1982). Ogden (1985) describes a dramatic change in the growth form of kauris when the tree reaches *dbh* 50 – 60 cm. At this stage the kauri sheds its lower branches and develops an open spreading crown above its associates. *Podocarpus falcatus* and *Podocarpus latifolius* have characters similar to *Araucaria* and *Agathis australis*, being long-lived conifers capable of canopy dominance. *Podocarpus falcatus* and *Podocarpus latifolius* are also emergent and sparsely branched with foliage that has little interference with light reaching the canopy.

This study addresses the following questions. Is the basal area of plots with large *Podocarpus* trees larger than the basal area of plots without *Podocarpus* trees?
What is the effect of comparing the total basal area to the basal area of all *Podocarpus* trees, rather than comparing it to only the big *Podocarpus* trees? Is there a difference between plots with big *Podocarpus* trees and plots without big *Podocarpus* trees? Does the range of the basal area at the eleven sites tell us about the carrying capacity of the forest?

If the basal area of these *Podocarpus* conifer giants is removed from a plot, is the basal area of the remaining species almost identical to other plots with no *Podocarpus* trees?

Does this then indicate that the *Podocarpus* component is 'additive' to the general forest matrix?

METHODS

Sampling

Plots were located at the intersections of a 100m x 80m grid that was randomly superimposed on the Knysna forest map. All trees with *dbh* $\geq$ 10cm were measured in circular plots with a radius of 11,3m and an area of approximately 400 m^2 (0.04 ha). The aspect, slope, date, forest type and species for each tree were also noted. The data, from over 2000 plots, were made available from the Department of Nature Conservation in Knysna (Appendix 2). These data were combined and collated into eleven sites: Groenkop, Bergplaas, Goudveld, Gouna, Diepwalle, Fisantehoek, Bloukrans, Lottering, Blueliliesbush, Witelsbos and Lilyvlei. The data from each site were organised to give a unique number for each plot and all analyses were calculated per plot for each of the eleven sites. A description of the collection methods (Appendix 1) and a tree code list (Appendix 3) accompanied the data.

dbh (diameter breast height)

There is a customary use of *dbh* $\geq$10 cm as a cut-off to define trees (Moinuddin & Ogden, 1987),(Midgley et al,1995),(Brown et al,1997). In this study stems $\geq$ 10cm were considered to be trees and large trees are defined as those with *dbh* $\geq$ 70 cm.

Regression analysis

The total basal area of *Podocarpus falcatus*, the total basal area of *Podocarpus latifolius*, the total basal area for the remaining species (i.e. all species excluding *Podocarpus falcatus* and *Podocarpus latifolius*) and the total basal area for all species, were regressed. The regression analysis involved correlating the basal area of *Podocarpus falcatus* and *Podocarpus latifolius* both separately and together, for each plot to i) the basal area of the rest of the species and ii) the total basal area of all the species. In other words when *Podocarpus falcatus* is correlated with the 'rest of the species' this means all species except *Podocarpus falcatus* but including *Podocarpus latifolius*.

The correlation results were also illustrated graphically for 6 of the sites : Gouna, Diepwalle, Lilyvlei, Witelsbos, Bergplaas and Blueliliesbush. These graphs were produced to give a general idea of basal area trends. It was felt that the 6 selected sites adequately represented the population.

Inclusion of the basal area of small Podocarpus trees with 'the remaining species'

Enright (1982) in his analysis of comparing basal areas to the remaining species, excluded the basal areas of all *A. hunsteinii*, not only big *A. hunsteinii*. Similarly in this analysis, when comparing basal area of *Podocarpus* with the basal area of the remaining species, all *Podocarpus* (both big and small) were excluded from 'the remaining species'. A separate analysis for 5 sites correlates the basal area of *Podocarpus* with the basal area of the remaining species, but includes the small *Podocarpus*. (The analysis in fact, compared basal areas of *Podocarpus* with the total basal area (of all species) but excluded the basal area of all the big *Podocarpus* species ($dbh \geq 70$ cm) from 'the total basal area'. Total basal area excluding big *Podocarpus* amounts to the same as 'the remaining species' including small *Podocarpus*.)

Comparison of plots with and without big trees

In the third part of these analyses, all plots with *Podocarpus* big trees at a site were compared to all plots without big trees at the same site. A t-test was used to ascertain whether there is a significant difference between those plots with big *Podocarpus* trees on them and those plots without big *Podocarpus* trees. Only 5 sites were selected for analysis ; Diepwalle, Lottering, Bloukrans, Blueliliesbush and Lilyvlei. These sites had the largest and most numerous big *Podocarpus* trees. Although Blueliliesbush has only 2 *Podocarpus falcatus* trees it was included in the analysis as these trees are exceptionally large with *dbh* 155.2cm and 142.3 cm.

Mean and median data

The mean and median basal area for each site were calculated and tabulated in a Box and Whiskers diagram. The variance of the mean at each site was compared to the population mean of that site to assess what kind of distribution could be expected, thus indicating the density of the forest. The range of the basal areas were compared and the carrying capacity discussed.

RESULTS

Podocarpus versus 'rest' of the species

Examination of the regression analysis indicates a weak negative correlation between the basal area of the rest of the species versus basal area of i) *Podocarpus falcatus*, ii) *Podocarpus latifolius* and iii) *Podocarpus falcatus* and *Podocarpus latifolius* combined (Table 1). When compared to the 'rest' of the basal areas, the plot basal area of *Podocarpus falcatus* and *Podocarpus latifolius* yielded a negative correlation for all regressions with two exceptions. *Podocarpus latifolius* had a zero correlation at Goudveld, r=0 and a positive correlation at Fisantehoek, r=0.12. As there are no large *Podocarpus latifolius* at Goudveld and only one specimen at Fisantehoek, this result is meaningless. A negative correlation between both the *Podocarpus* species versus the rest of the species was indicated in all the plots except Fisantehoek, which has a positive but insignificant correlation, r=0.12. The remaining correlation results ranged between r= –0.30 at Bergplaas and r= –0.12 at Goudveld (Graph 1a-6a).

TABLE 1 : KNYSNA TREE TOTALS AND BASAL AREA CORRELATIONS

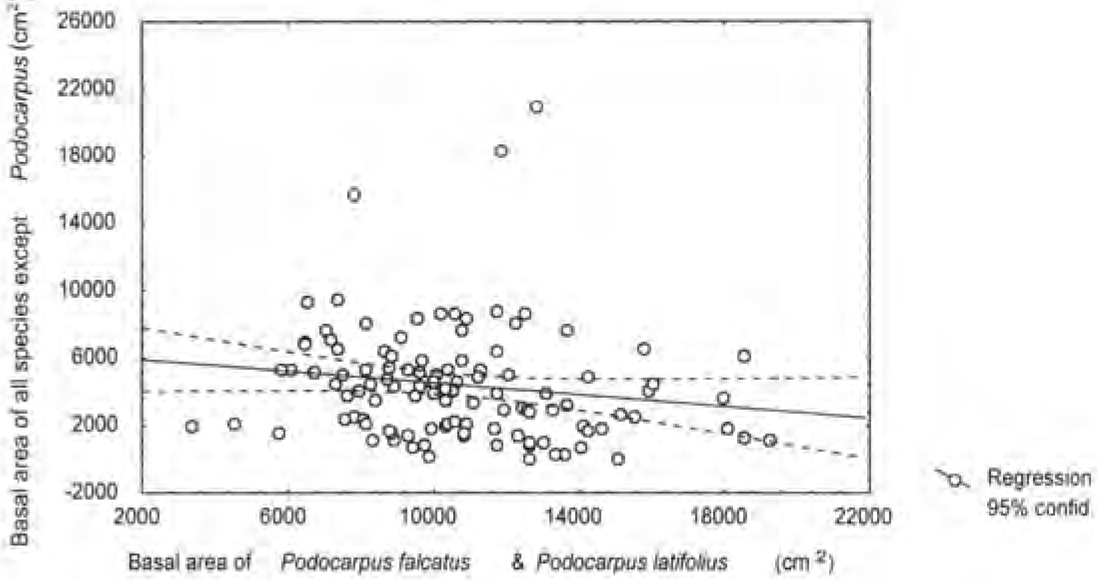
LOCALITY	TOTAL NUMBER OF TREES						Total	BASAL AREA CORRELATIONS					
	016 dbh <70cm	016 dbh ≥70cm	018 dbh <70cm	018 dbh ≥70cm	016 & 018	total all trees	plots per site	016 vs rest of the basal area	018 vs rest of the basal area	016 & 018 vs rest of the basal area	016 vs total of all basal area	018 vs total of all basal area	016 & 018 vs total of all basal area
GROENKOP	11	0	191	1	202	1268	48	-0.14	-0.24	-0.24	-0.06	0.29	0.25
BERGPLAAS	119	2	853	0	972	6114	218	-0.15	-0.29	-0.30	0.12	0.18	0.22
GOUDVELD	50	3	238	0	288	3399	123	-0.15	0.00	-0.12	0.61	0.27	0.67
GOUNA	36	8	421	5	457	3162	121	-0.10	-0.25	-0.17	0.57	0.30	0.69
DIEPWALLE	260	16	2651	11	2911	14407	495	-0.03	-0.27	-0.18	0.43	0.29	0.53
FISANTEHOEK	29	0	353	1	382	2254	104	-0.04	0.12	0.12	0.11	0.53	0.54
BLOUKRANS	13	3	449	7	462	3227	89	-0.05	-0.21	-0.21	0.39	0.39	0.55
LOTTERING	93	17	1348	27	1441	10186	322	-0.15	-0.26	-0.25	0.43	0.33	0.56
BLUELILIESBUSH	34	2	197	2	231	2235	95	-0.31	-0.10	-0.30	0.20	0.12	0.23
WITELSBOS	42	1	112	0	154	735	30	-0.27	-0.27	-0.27	0.51	0.00	0.51
LILYVLEI	26	8	326	22	352	2496	103	-0.10	-0.25	-0.20	0.34	0.41	0.56

016 ***Podocarpus falcatus***
018 ***Podocarpus latifolius***

Graph 1 (a) : GOUNA BASAL AREA CORRELATIONS

p = 0.097 n = 112

Correlation: r = -.1575



Graph 2 (a) : DIEPWALLE BASAL AREA CORRELATIONS

p = .000 n = 486

Correlation: r = -.1834

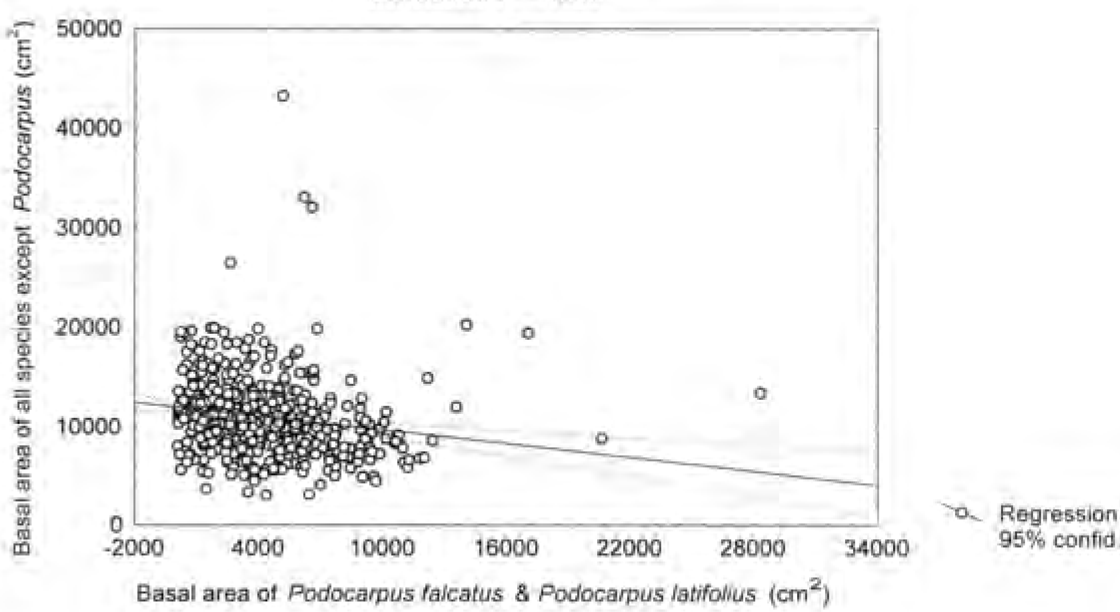


Figure 3 (a) : LILYVLEI BASAL AREA CORRELATIONS

p = .048 n = 97

Correlation: r = -.2010

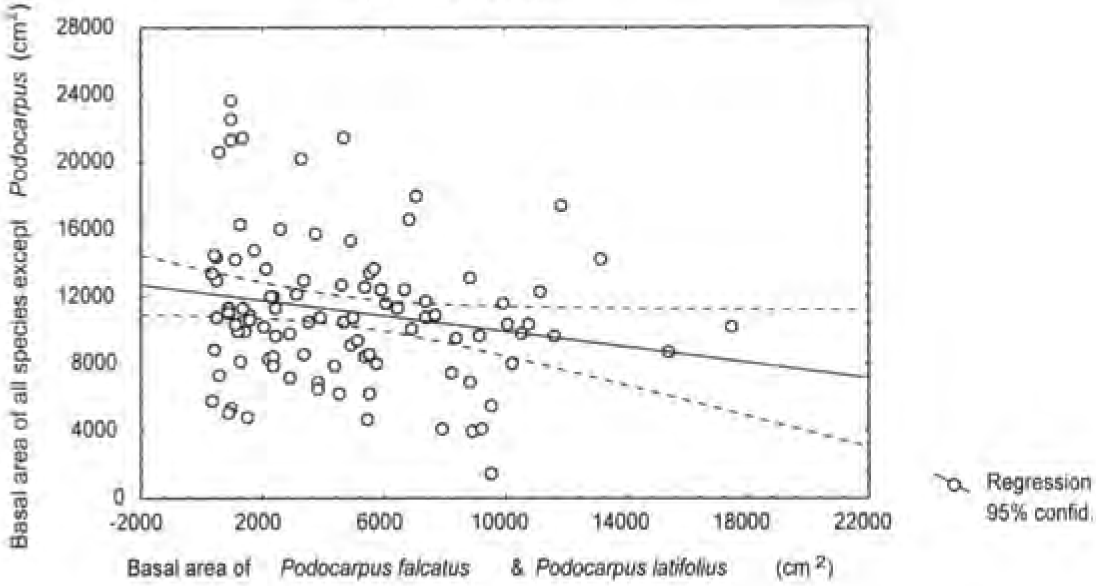


Figure 4 (a) : WITELS BASAL AREA CORRELATIONS

p = .185 n = 25

Correlation: r = -.2742

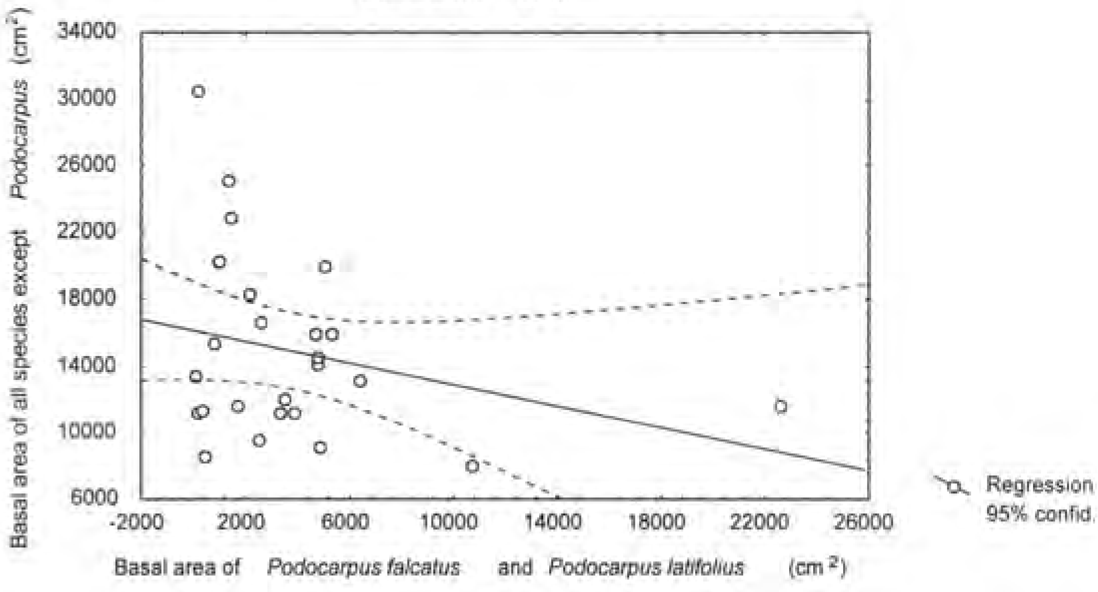


Figure 5 (a) : BERGPLAAS BASAL AREA CORRELATIONS

p = -0.30   n = 207

Correlation: r = -.2998

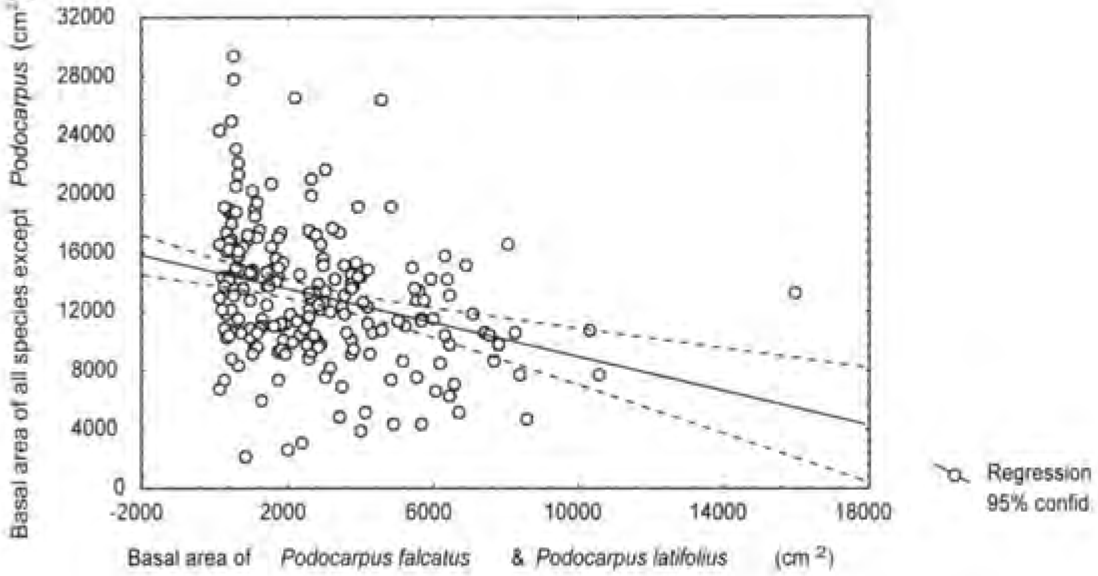


Figure 6 (a) : BLUELILIESBUSH BASAL AREA

p = 0.008   n = 78

Correlation: r = -.2969

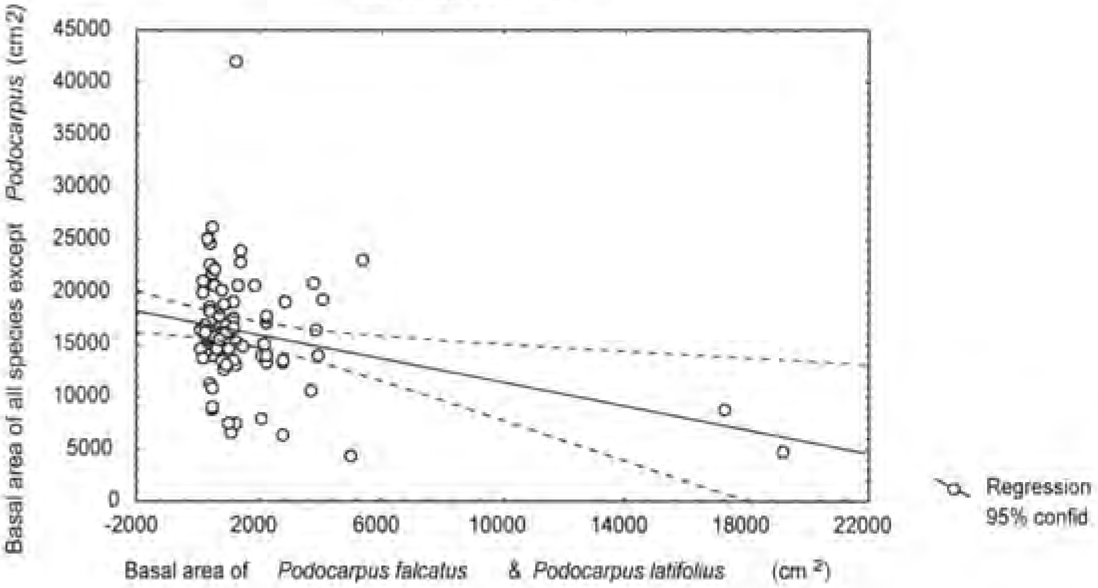


Figure 1 (b) : GOUNA BASAL AREA CORRELATIONS

p < .0500 N = 112

Correlation: r = .69047

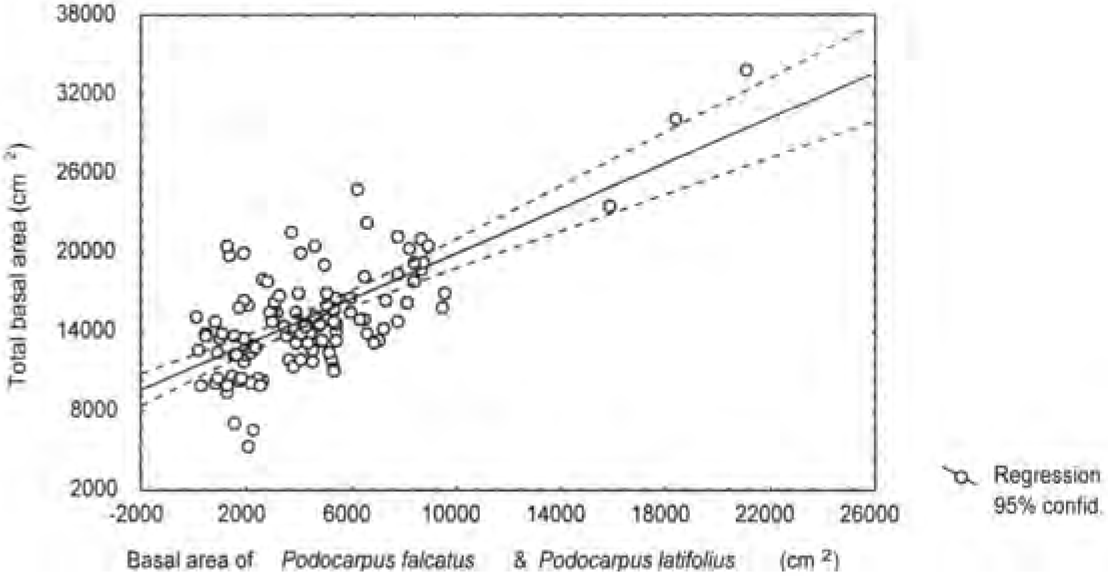


Figure 2 (b) : DIEPWALLE BASAL AREA CORRELATIONS

p = .000 n = 486

Correlation: r = .52508

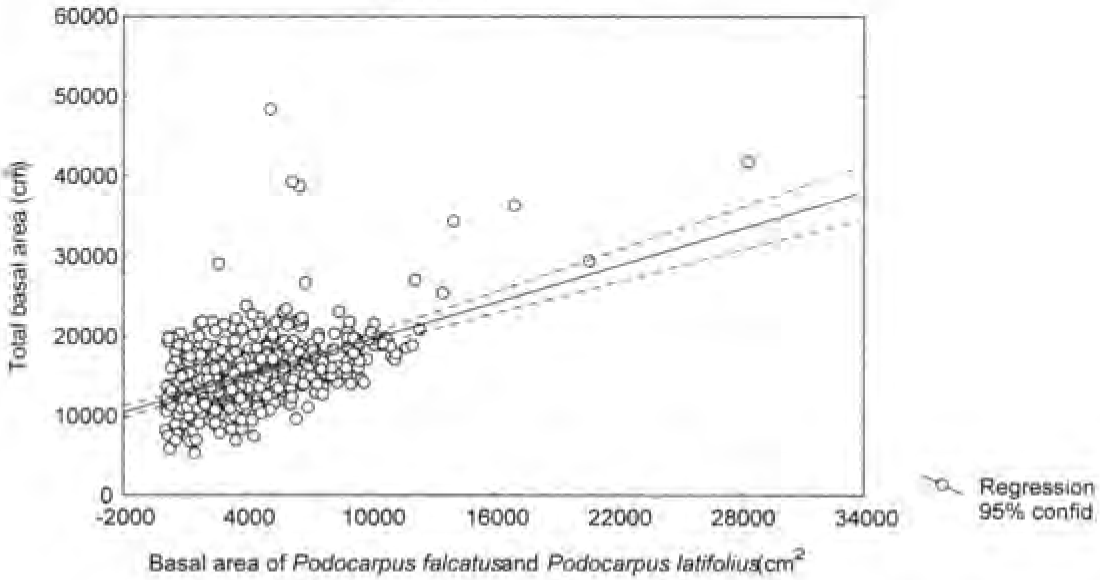


Figure 3 (b) : LILYVLEI BASAL AREA CORRELATIONS

p = .000 n = 98

Correlation: r = .56056

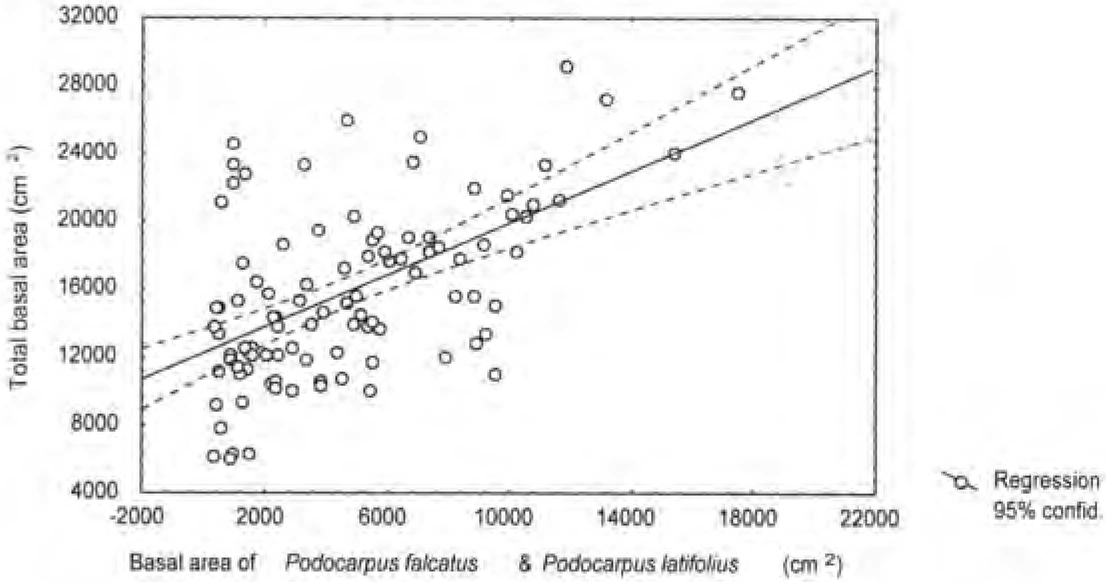


Figure 4 (b) : WITELS BASAL AREA CORRELATION

p = 0.009 n = 25

Correlation: r = .51207

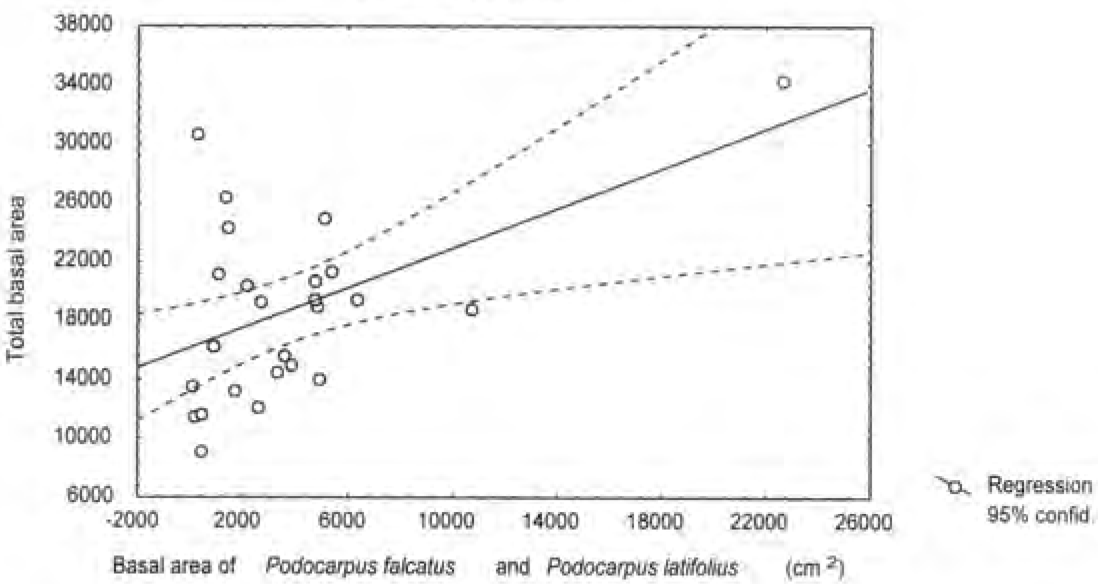


Figure 5 (b) : BERGPLAAS BASAL AREA CORREALTIONS

p = 0.001 n = 207

Correlation: r = .22427

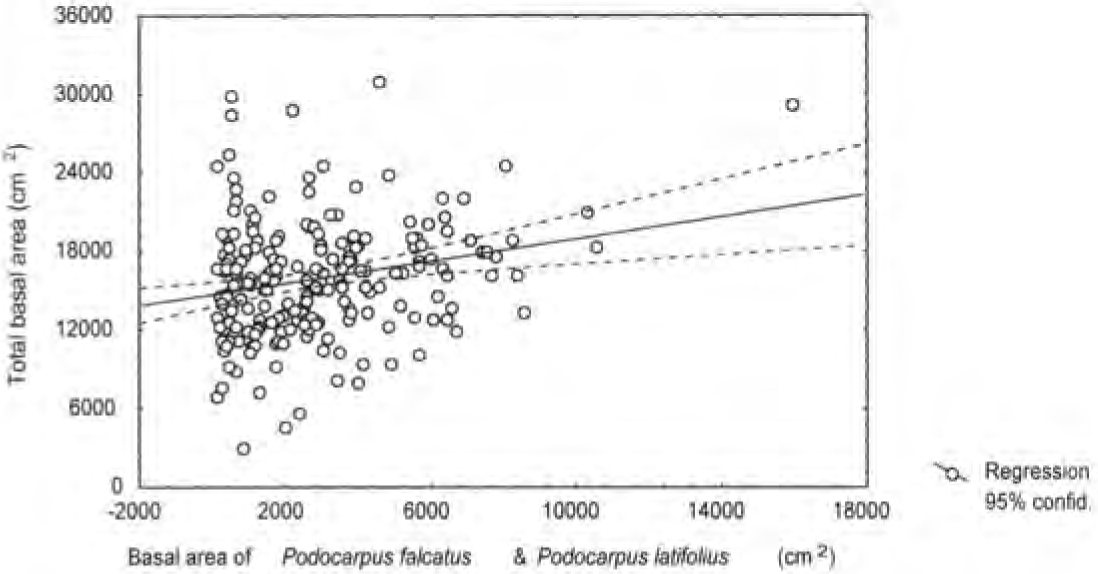
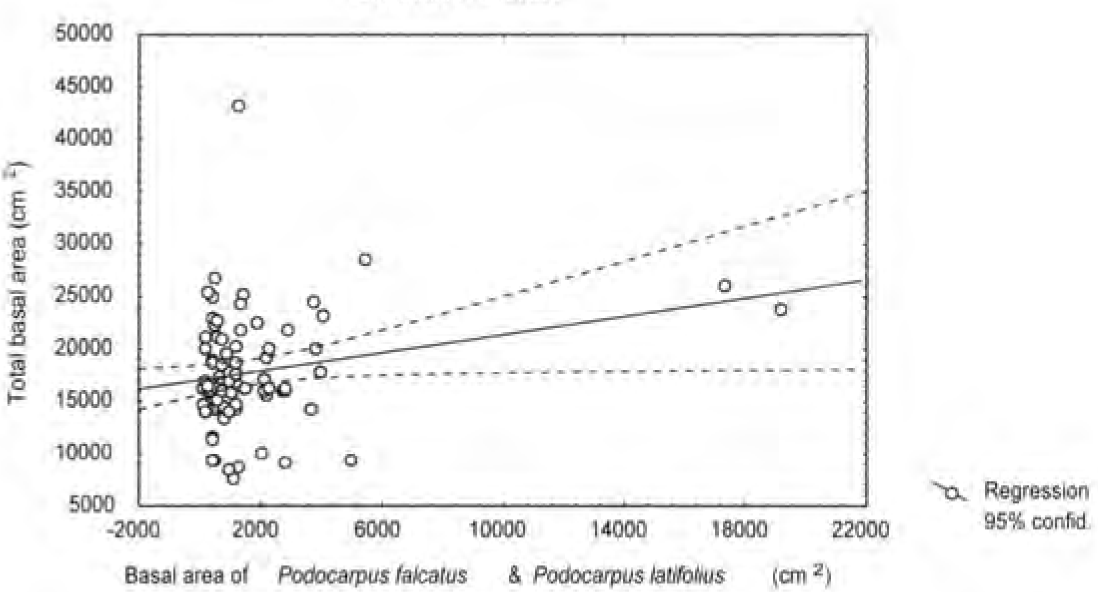


Figure 6 (b) : BLUELILIESBUSH BASAL AREA CORRELATIONS

p = 0.040 n = 78

Correlation: r = .23258



The p-values indicate that of the 10 sites with positive regressions only Bergplaas, Diepwalle, Lottering, Blueliliesbush and Lilyvlei indicated significant positive regressions (Table 2).

regression analysis with the total of all species

Of the 11 sites examined virtually all *Podocarpus falcatus* and *Podocarpus latifolius* analysed both separately and together indicate that their basal area is positively correlated with the total basal area (Table 1). There is one exception for *Podocarpus falcatus* at Groenkop r = -0.06, but here there is no large *Podocarpus falcatus*. The basal area of *Podocarpus falcatus* and *Podocarpus latifolius* versus the total basal area indicate a significantly positive correlation at all 11 sites (Table 2). This indicates that as the basal area of *Podocarpus falcatus* and *Podocarpus latifolius* increases so does the total basal area (Graph 1b-6b).

TABLE 2 : KNYSNA TREE TOTALS AND BASAL AREA CORRELATIONS

LOCALITY	Total number plots	*PODOCARPUS FALCATUS & PODOCARPUS LATIFOLIUS* vs All species except 016 & 018 p-value	correlation	vs Total basal area p-value	correlation
GROENKOP	44	0.11	-0.24	0.097	0.25
BERGPLAAS	207.00	0.00 #	-0.30	0.001 #	0.22
GOUDVELD	104.00	0.23	-0.12	0.00 #	0.67
GOUNA	112.00	0.10	-0.17	0.00 #	0.69
DIEPWALLE	486.00	0.00 #	-0.18	0.00 #	0.53
FISANTEHOEK	71.00	0.31	0.12	0.00 #	0.54
BLOUKRANS	81.00	0.07	-0.21	0.00 #	0.55
LOTTERING	305.00	0.00 #	-0.25	0.00 #	0.56
BLUELILIESBUSH	78.00	0.008 #	-0.30	0.04 #	0.23
WITELSBOS	25.00	0.19	-0.27	0.009 #	0.51
LILYVLEI	97.00	0.048 #	-0.20	0.00 #	0.56

# denotes significant at $p < 0.05$

excluding all large Podocarpus from analysis

Enright (1982) in his comparison of basal areas excluded the basal areas of all *Auraucaria*, big and small, from his analysis. To test the effect of excluding all *Podocarpus* from the analysis of 'the remaining species', I calculated the correlation between the *Podocarpus* versus the total basal area but excluding large *Podocarpus* from the analysis (Table 3).

These regressions show a positive correlation for all five plots except Blueliliesbush which has r = -0.20. In all instances, the effect of including the small *Podocarpus* with the remaining species, has influenced the correlation values. The regressed values at 4 sites change from a negative regression (small *Podocarpus* excluded) to a positive regression (small Podocarpus included) and this indicates that the exclusion of small *Podocarpus* trees from 'the remaining species' does impact on the basal area.

TABLE 3 : BASAL AREA OF *PODOCARPUS FALCATUS* & *PODOCARPUS LATIFOLIUS* VERSUS BASAL AREA OF 'REST' BUT INCLUDING SMALL PODOCARPUS TREES

LOCALITY	016 & 018 vs rest of species	016 & 018 vs total excluding big trees ≥ 70 cm	016 & 018 vs total basal area
DIEPWALLE	-0.18	0.39	0.53
BLOUKRANS	-0.21	0.18	0.55
LOTTERING	-0.25	0.07	0.56
BLUELILIESBUSH	-0.30	-0.20	0.23
LILYVLEI	-0.20	0.14	0.56

016 *Podocarpus falcatus* 018 *Podocarpus latifolius*

Comparison of plots with big trees and plots without big trees

In the third part of the analysis t-tests were used to compare the difference between plots with big *Podocarpus* trees and those plots having no big *Podocarpus* trees. The t-test analysis show that the plots with big *Podocarpus* trees consistently have a higher basal area than those without *Podocarpus* trees and this difference was significant for Diepwalle, Lottering, Bloukrans and Lilyvlei (Table 4). The one exception being Blueliliesbush which has only two large *Podocarpus latifolius* and both have a small *dbh* (70.7cm & 78.8 cm).

TABLE 4 : t-Test results for plots with big trees versus plots without big trees

Locality & tree species	Mean : plots with Group 1	Mean : plots with no big trees Group 2	t-value	degree of freedom	p values	Valid N group 2	Valid N group 1	Std. Dev. group 2	Std. Dev group 1	F-ratio variances
DIEPWALLE										
016*	23133.27	15022.19	-7.26440	495	0.0000 #	16	481	8390.26	4208.11	3.97536
018*	18217.82	15216.90	-2.13924	495	0.0329 #	11	486	3939.89	4613.41	1.37112
016 & 018*	21130.68	14947.40	-7.09535	495	0.0000 #	27	470	7255.43	4188.97	2.99994
LOTTERING										
016*	25942.73	17098.18	7.54959	320	0.0000 #	15	307	4827.99	4411.32	1.19783
018*	21976.58	17138.99	5.01902	320	0.0000 #	25	297	4660.24	4625.80	1.01494
BLOUKRANS										
016*	24773.16	17046.58	2.57898	87	0.0116 #	3	86	10919.74	4881.25	5.00452
018	20610.95	17024.99	1.75080	87	0.0835	7	82	4167.75	5270.06	1.59892
016 & 018*	21859.62	16573.27	3.25807	87	0.0016 #	10	79	6490.02	4604.84	1.98638
BLUELILIESBOS										
016*	25116.48	17357.51	-2.02613	93	0.0456 #	2	93	1602.38	5384.80	11.29306
018	16393.50	17545.10	-0.29444	93	0.7691	2	93	9873.10	5405.31	3.33630
016 & 018	20754.99	17378.70	1.21660	93	0.2268	4	91	7662.38	5341.93	2.05745
LILYVLEI										
016*	21878.99	15081.37	-3.60062	101	0.0002 #	8	95	6284.07	4735.06	1.76129
018*	18499.11	14913.01	-2.88349	101	0.0048 #	20	83	4611.35	5077.03	1.21217

 # denotes significant at $p < 0.05$

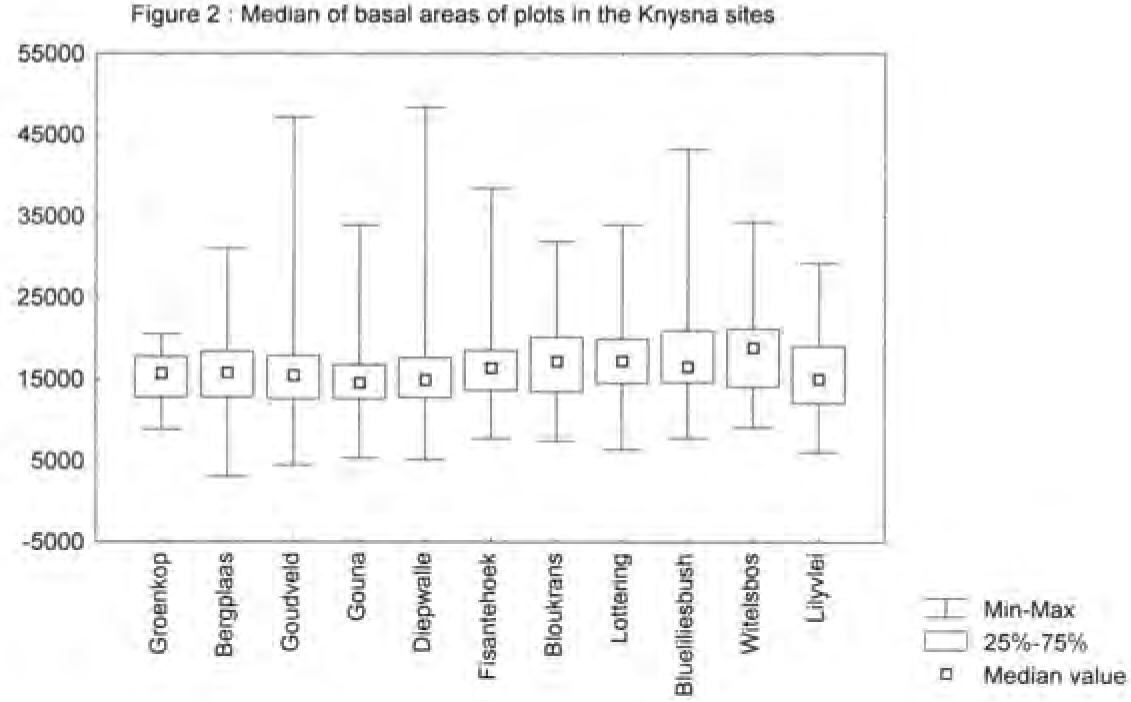
016 *Podocarpus falcatus* 018 *Podocarpus latifolius*

mean and median values at each site

The median and mean values of the basal areas of the plots at each site were examined and the basal area ranges from 11662 – 42673 cm^2 with the maximum basal area values ranging from 20574 – 47180 cm^2. This suggests that the carrying capacity at each site varies quite considerably (Figure 2).

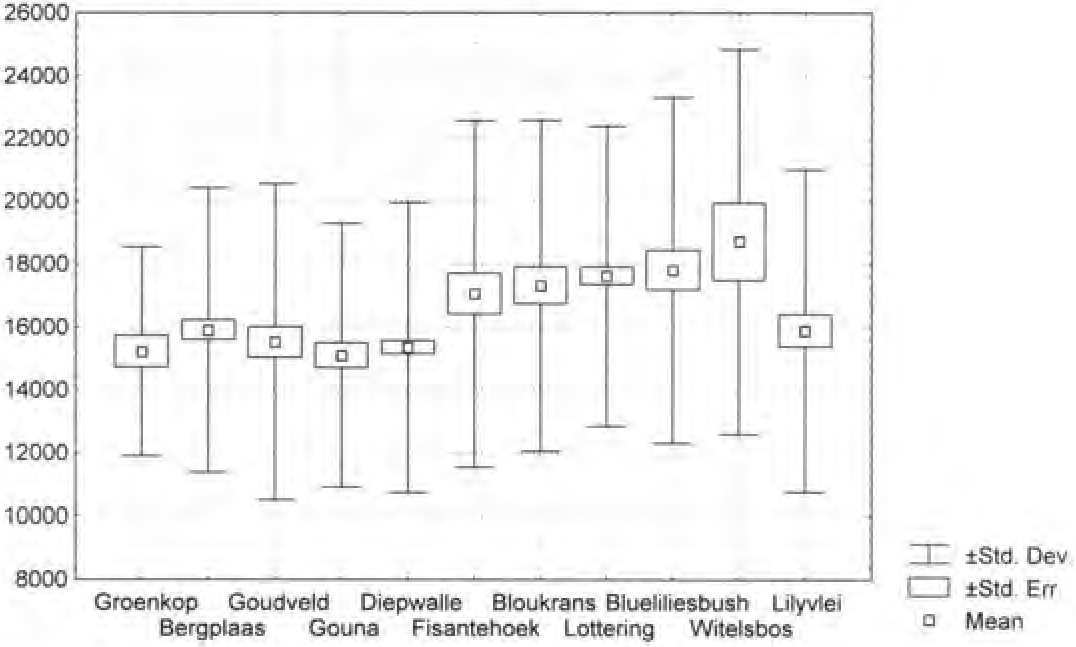
The variance was calculated and compared to the population mean and although a clustered, aggregated or contagious distribution was indicated, analysis involving the Poisson distribution should ideally use a sample distribution with a small mean. If the mean is too large then the Poisson too closely resembles the binomial, as well as the normal, distribution (Zar,1999). The mean > 10 and these results were therefore not regarded.

Figure 2 : Median of basal areas of plots in the Knysna sites



Although the means of each site are fairly consistent, (14886 – 17823 cm^2), there does seem to be much variation of the mean within each site (Figure 3). This indicates a trend towards an overall mean density but considerable variation is still evident.

Figure 3 : Mean of total basal areas of plots in the Knysna sites



DISCUSSION

The analysis of *Podocarpus falcatus* and *Podocarpus latifolius* versus the 'rest' of the species yielded mainly a negative correlation. This indicates weak but not always significant competition. If *Podocarpus falcatus* and *Podocarpus latifolius* provide an additive basal area one would have expected to find no negative correlation between these data; thus indicating no competition. These regression values are however relatively low and at 5 of the 11 sites the regressions are insignificant. This indicates that competition, if any, is relatively weak and would be in support of the 'additive basal area' idea.

The *Podocarpus falcatus* and *Podocarpus latifolius* analysed both separately and together, indicate that their basal area is significantly positively correlated with the total basal area. This leads us to conclude that as the basal area of *Podocarpus falcatus* and *Podocarpus latifolius* increases so does the total basal area. This supports an 'additive' hypothesis.

Enright (1982) argues that the proportion of *A. hunsteinii* basal areas made up of sub-canopy individuals is usually negligible (<5%). I however, feel that exclusion of the basal areas of small *Podocarpus* trees (*dbh* < 70 cm) is inaccurate. The inclusion of small *Podocarpus* trees in 'the remaining species', when comparing basal areas, changed the regression from a negative to a positive regression so they do contribute to the basal area. Only the basal area of a large, emergent *Podocarpus* tree should constitute as an 'additive'.

If small *Podocarpus* had been included in the 'remaining the species' the very weak negative correlations, may have indicated no correlation and thus no competition. This explanation is in supports of the 'additive' idea.

The history of the Knysna forests up till 1939 is one of reckless exploitation (von Breitenbach,1974). Over the years some sites may have been more extensively harvested for big trees than others and the absence of very large trees could influence these results. Lilyvlei site is considered primeval forest and as far as is known, is the only extensive part of the Knysna forest that has never been exploited (Midgley,1995). These undisturbed plots should therefore yield the greatest information, but Lilyvlei results were in fact comparable to the other sites.

In the third part of the analysis t-tests results show that with one exception, the plots with big *Podocarpus* trees consistently have a significantly higher basal area than those plots without *Podocarpus* trees. Blueliliesbush is the exception and has a very small sample size with two *Podocarpus latifolius*. This possibly accounts for the mean basal area for big tree plots being lower than for plots without big trees at this site. However, the large *Podocarpus falcatus* have an exceptionally large *dbh* at Blueliliesbush and the t-test indicates a significant difference ($p>0.05$) between those plots.

The median and mean basal area for each site indicates that they are fairly similar, although the range of basal area per plot is fairly large. One can infer that although the mean basal area per plot can differ dramatically, thus indicating a varying carrying capacity, there is a trend for the plots have a similar density.

There is a significant difference in the basal area between plots with big trees and plots without big trees and regression analysis indicates a significantly positive correlation between the basal area of *Podocarpus* and the total basal area. These results both indicate that large *Podocarpus falcatus* and *Podocarpus latifolius* are producing a larger basal area per plot and that an 'additive basal area' hypothesis is supported.

CONCLUSION

What does the difference in basal areas between sites actually tell us? Do these analyses in fact tell us about competition? We know that large trees play an important role in forest dynamics and that large trees have the potential to accumulate significant quantities of additional biomass if left unharvested (Brown et al,1997). In one study large trees accounted for 2% of stems, 23% of basal area and 27% of above-ground biomass (Clark & Clark,1997). A small diameter increase can cause a substantial volume and biomass increase and the biomass of one tree 150 cm in diameter equals that of approximately 607 trees 10 cm in diameter (Clark & Clark, 1996). A tree with a *dbh* 70cm has a basal area $4 \times$ that of a tree *dbh* 35cm and yet this large basal area does not mean that a tree half the size of a large one uses four times more its resources?

It is interesting to note that the median and mean basal area examined at 11 sites in the Knysna forest are relatively constant although the range is quite high. The basal area

m^2ha^{-1} in the Knysna forest, 40 to 50 m^2 ha^{-1} (Midgley,1997) appears to be higher than that in the tropics. The basal area values in beech forest *Nothofagus* commonly ranges between 30 and 80 m^2ha^{-1} while the average value for kauri forests is higher than that recorded for tropical rainforests of similar structure which rarely exceed 60 m^2ha^{-1} (Moinuddin & Ogden,1987). Why is the carrying capacity of tropical forests so much lower? Does a tropical forest in fact reach a carrying capacity or is it always adjusted by disturbance?

Disturbance in the Knysna forest is less than in the tropics (Midgley, pers comm) and does this indicate that the carrying capacity in the Knysna forest is higher due to lack of disturbance or higher due to the presence of very big trees? Do these conifers make such a substantial contribution to the basal areas of the forests?

Enright & Hill (1995) emphasized that it is the conifer component as being additive to the general forest matrix. It was thought that the emergent conifer is not competing strongly with the other trees for space and because of their sparse canopy architecture, does not capture much light. In this analysis when *Podocarpus falcatus* and *Podocarpus latifolius* were analysed separately, the truly emergent species *Podocarpus falcatus* did not always yield results that supported the additive idea, although the combined *Podocarpus* species did. Is an increased basal area not merely a result of the presence of an exceptionally large tree and not necessarily an emergent tree?

An interesting question is raised. Does the carrying capacity vary so considerably because all big trees provide an 'additive' basal area? It would be interesting to determine the number of trees in a plot and assess whether the presence of a big tree significantly reduces the number of trees on that plot and how the basal area of a big tree impacts on the basal area of that plot.

However it is clear from all the evidence in this study that *Podocarpus* species in the Knysna forest support an 'additive basal area' hypothesis.

ACKNOWLEDGEMENTS

I would like to thank Dr. A. Seydack and Graham Durrheim of Water Affairs & Forestry at Knysna for kindly allowing us to access to their invaluable data base. I would also like to thank my supervisor, Jeremy Midgley for his time and extreme patience and above all his continuing inspiration. Thank you.

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Appendix 1 : PSP & TSP DATA

Surveys were carried out in selected timber production compartments prior to harvesting over a period of approximately 5 years, from September 1984 to August 1989. Refer to the attached file: PSP & TSP Data Summary.

Plots were laid out in those parts of the compartments considered suitable for harvesting.

Plots were located at the intersections of a 100m x 80m grid that was randomly superimposed on the forest map. Plot lines were usually 100m apart and orientated along the true north-south line. Permanent and temporary plots (PSPs and TSPs) were usually located on alternate lines: PSPs usually on the even-numbered lines and TSPs usually on the odd-numbered lines.
Plots were originally laid out 80m apart on the plot lines, with plot numbers increasing from south to north.

Plots are circular with a radius of 11,3m and an area of approximately $400m^2$.
The sampling intensity was approximately 5%.
The sampling intensity was later increased to 7,5% when TSPs were laid out 40m apart on the TSP plot lines, thereby doubling the number of TSPs.
These additional TSPs were numbered by adding an "A" to the plot number of the preceding plot.

Please note that groups of adjacent compartments were often surveyed as a unit, although the data is provided separately for each compartment. It is therefore possible that suitable neighbouring plots to those with large Kalander trees may be found in the data files for adjacent compartments.
All trees with DBH $\geq$ 10cm were measured.

VARIABLES

The variables in the data sets are explained briefly below:

A. STATE FOREST

A 3-digit code was used, as follows:

Bergplaas	203
Diepwalle	209
Fisantehoek	211
Goudveld	212
Gouna	213
Groenkop	228
Bloukrans	403
Blueliliesbush	404
Lottering	409
Witelsbos	413

B. BLOCK

A ⇒ 01, B ⇒ 02, etc.

C. COMPARTMENT

Four digits, e.g. 3c ⇨ 0303, 14a ⇨ 1401, etc.

D. **LINE** Two digits

E. **PLOT** Two digits

F. ASPECT

A single digit code as follows:

Direction	True bearing	Code
N	337,5° - 22,5°	1
NE	22,5° – 67,5°	2
E	67,5° – 112,5°	3
SE	112,5° – 157,5°	4
S	157,5° – 202,5°	5
SW	202,5° – 247,5°	6
W	247,5° – 292,5°	7
NW	292,5° – 337,5°	8
Level		0

G. **SLOPE** Two digits: Degrees

H. MONTH of the survey

I. **YEAR** of the survey

J. FOREST TYPE

Medium-moist High Forest	mm
Moist High Forest	m

K. SPECIES

3-digit number code based on the National Tree List numbers. Refer to the attached file TREE LIST.

L. DBH : Diameter at Breast Height (1,3m) in cm.

Appendix 2 : PSP / TSP DATA SUMMARY

FOREST	COMPARTMENT	YEAR OF SURVEY	NUMBER OF PSP's	NUMBER OF TSP's	TOTAL PLOTS	EFFECTIVE AREA (HA) OF COMP.	EXCEL FILE NAME
Groenkop	B3c	1986/87	12	3	15	10.2	grb03c86
Groenkop	B5a	1986/87	7	6	13	8.8	grb05a86
Groenkop	B6b	1986/87	7	13	20	17.9	grb06b86
Groenkop	B1d	1988/89	-	-	-	-	Data missing
Groenkop	B2a	1988/89	-	-	-	-	Data missing
Groenkop	B3d	1988/89	-	-	-	-	Data missing
Bergplaas	A4a	1985/86	13	9	22	14.6	bga04a85
Bergplaas	B14a	1986/87	11	11	22	18.3	bgb14a86
Bergplaas	B14b	1987/88	8	7	15	10.9	bgb14b87
Bergplaas	B14c	1987/88	13	19	32	22.6	bgb14c87
Bergplaas	B25c	1988/89	20	37	57	30.6	bgb25c88
Bergplaas	A6b	1989/90	9	16	25	14.4	bga06b89
Bergplaas	A7a	1989/90	13	32	45	21.6	bga07a89
Goudveld	F2e	1985/86	9	10	19	14.9	gvf02e85
Goudveld	F2f	1985/86	11	10	21	14.4	gvf02f85
Goudveld	F2d	1987/88	6	27	33	12.0	gvf02d87
Goudveld	F4f	1989/90	15	35	50	20.2	gvf04f89
Gouna	D2c	1985/86	36	36	72	61.5	gnd02c85
Gouna	D2d	1986/87	16	12	28	22.3	gnd02d86
Gouna	D3a	1987/88	15	17	32	27.4	gnd03a87
Gouna	F4d	1988/89	29	58	87	47.0	gnf04d88
Gouna	F2b	1989/90	18	44	62	30.7	gnf02b89
Gouna	F4b	1989/90	11	23	34	19.1	gnf04b89
Diepwalle	A1a	1985/86	5	7	12	9.8	dwa01a85
Diepwalle	A1b	1985/86	10	5	15	10.5	dwa01b85
Diepwalle	A1c	1985/86	20	16	36	28.5	dwa01c85
Diepwalle	D12a	1985/86	7	10	17	10.8	dwd12a85
Diepwalle	D12b	1985/86	12	8	20	14.4	dwd12b85
Diepwalle	D13e	1985/86	1	3	4	3.3	dwd13e85
Diepwalle	B1b	1986/87	10	9	19	15.8	dwb01b86
Diepwalle	B1h	1986/87	9	5	14	13.5	dwb01h86
Diepwalle	D12c	1986/87	5	5	10	9.2	dwd12c86
Diepwalle	D12d	1986/87	7	11	18	12.2	dwd12d86
Diepwalle	A4d	1987/88	11	12	23	16.6	dwa04d87
Diepwalle	C11c	1987/88	10	10	20	15.0	dwc11c87
Diepwalle	C11e	1987/88	13	7	20	15.0	dwc11e87
Diepwalle	D5b	1987/88	19	25	44	34.7	dwd05b87
Diepwalle	A6c	1988/89	15	25	40	22.4	dwa06c88
Diepwalle	C1b	1988/89	4	9	13	7.0	dwc01b88
Diepwalle	C1c	1988/89	11	18	29	14.1	dwc01c88
Diepwalle	C1d	1989/90	10	20	30	15.6	dwc01d89
Diepwalle	C2b	1989/90	7	13	20	11.0	dwc02b89
Diepwalle	C2c	1989/90	9	28	37	18.0	dwc02c89
Diepwalle	C3b	1989/90	5	7	12	7.3	dwc03b89
Diepwalle	C3c	1989/90	13	31	44	21.4	dwc03c89
Fisantehoek	B3b	1986/87	10	12	22	19.3	kkb03b86
Fisantehoek	B3e	1986/87	17	19	36	29.1	kkb03e86
Fisantehoek	B6a	1988/89	7	15	22	11.1	kkb06a88
Bloukrans	E12c	1988/89	10	21	31	17.9	bke12c88
Bloukrans	D11a	1989/90	22	38	60	33.3	bkd11a89
Lottering	J4e	1985/86	14	18	32	24.0	loj04e85
Lottering	J4f	1985/86	10	8	18	16.7	loj04f85
Lottering	J4d	1986/87	16	15	31	30.6	loj04d86
Lottering	J4g	1986/87	15	11	26	21.1	loj04g86
Lottering	J1c	1987/88	11	10	21	17.1	loj01c87
Lottering	J8d	1987/88	50	42	92	74.8	loj08d87
Lottering	M5b	1988/89	25	51	76	42.3	lom05b88
Lottering	M5d	1988/89	11	31	42	22.5	lom05d88
Lottering	M5c	1989/90	-	-	-	-	Data missing
Bluelliesbush	E7a	1986/87	11	9	20	19.2	ble07a86
Bluelliesbush	E7b	1986/87	8	7	15	11.7	ble07b86
Bluelliesbush	E7c	1986/87	10	7	17	15.4	ble07c86
Bluelliesbush	E7d	1987/88	8	9	17	14.1	ble07d87
Bluelliesbush	E7e	1987/88	10	16	26	23.9	ble07e87
Witelsbos	D2a	1985/86	10	11	21	14.9	wed02a85
Lilyvlei	G1a	1985	33	33	66		gng01a85
Lilyvlei	G1b	1991	70	70	140		gng01b91
TOTAL			870	1162	2032	1224.5	

APPENDIX 3 : TREE LIST FOR THE INDIGENOUS FORESTS OF THE SOUTHERN CAPE

Number Code	Abbreviation	Scientific Name	Family	English Name	Afrikaans Name
002		Cyathea capensis	CYATHEACEAE	Forest Tree Fern	Bosboomvaring
016	Kal	Podocarpus falcatus	PODOCARPACEAE	Outeniqua Yellowwood	Kalander
018	Geel	Podocarpus latifolius	PODOCARPACEAE	Real Yellowwood	Opregte Geelhout
020		Widdringtonia nodiflora	CUPRESSACEAE	Mountain Cypress	Bergsipres
032		Strelitzia alba	STRELITZIACEAE	Cape Wild Banana	Kaapse Wildepiesang
038		Myrica serrata	MYRICACEAE	Lance-leaved Waxberry	Smalblaarwasbessie
039	WSH	Celtis africana	ULMACEAE	White Stinkwood	Witstinkhout
49		Ficus burtt-davyi	MORACEAE	Veld Fig	Veldvy
050	BTV	Ficus sur	MORACEAE	Broom Cluster Fig	Besemtrosvy
074	Ter	Faurea macnaughtonii	PROTEACEAE	Terblans Beech	Terblans
118	SH	Ocotea bullata	LAURACEAE	Stinkwood	Stinkhout
134		Maerua racemulosa	CAPPARACEAE	Forest Bush-cherry	Witboshout
139	WBH	Pittosporum viridiflorum	PITTOSPORACEAE	Cheesewood	Kasuur; Witboekenhout
140	RE	Cunonia capensis	CUNONIACEAE	Red Alder	Rooiels
141	WE	Platylophus trifoliatus	CUNONIACEAE	White Alder	Witels
142	OB	Trichocladus crinitus	HAMAMELIDACEAE	Black Witch-hazel	Onderbos
143		Trichocladus ellipticus	HAMAMELIDACEAE	White Witch-hazel	Wittowerhaselaar
147	RSH	Prunus africana	ROSACEAE	Red Stinkwood	Rooistinkhout
201		Schotia afra var. afra	FABACEAE	Karroo Boer-bean	Karooboerboon
204		Schotia latifolia	FABACEAE	Bush Boer-bean	Bosboerboon
221	Keur	Virgilia oroboides subsp.ferruginea	FABACEAE	Blossom Tree	Keurboom
221.1		Virgilia divaricata	FABACEAE	Pink Blossom Tree	Pienk Keurboom
253		Zanthoxylum capense	RUTACEAE	Small Knobwood	Kleinperdepram
254	PP	Zanthoxylum davyi	RUTACEAE	Knobwood	Perdepram
256	WK	Calodendrum capense	RUTACEAE	Cape Chestnut	Wildekastaing
261	WYH	Vepris lanceolata	RUTACEAE	White Ironwood	Witysterhout
265		Clausena anisata	RUTACEAE	Horsewood	Perdepis
298	Ess	Ekebergia capensis	MELIACEAE	Cape Ash	Essenhout
307	KH	Lachnostylis hirta	EUPHORBIACEAE	Coalwood	Koolhout
366		Laurophyllus capensis	ANACARDIACEAE	Iron Martin	Ystermartiens
380	BTB	Rhus chirendensis	ANACARDIACEAE	Red Currant	Bostaaibos
380.1		Rhus crenata	ANACARDIACEAE	Dune Crowberry	Duinekraaibessie
383.2		Rhus glauca	ANACARDIACEAE	Blue Kuni-bush	Bloukoeniebos
388		Rhus longispina	ANACARDIACEAE	Thorny Currant	Doringtaaibos
388.1		Rhus lucida forma lucida	ANACARDIACEAE	Glossy Currant	Blinktaaibos
394		Rhus tomentosa	ANACARDIACEAE	Real Wild Currant	Korentebos
395		Rhus undulata	ANACARDIACEAE	Kuni-bush	Koeniebos
397	WH	Ilex mitis	AQUIFOLIACEAE	Cape Holly	Without
398	Rsy	Maytenus acuminata var.acuminata	CELASTRACEAE	Red Silky Bark	Rooisybas
399	Pdor	Maytenus heterophylla	CELASTRACEAE	Common Spike-thorn	Gewone Pendoring
399.3		Maytenus nemorosa	CELASTRACEAE	White Forest Spike-thorn	Witbospendoring
401	Sw	Maytenus peduncularis	CELASTRACEAE	Cape Blackwood	Kaapse Swarthout
406		Pterocelastrus rostratus	CELASTRACEAE	Red Candlewood	Rooikershout
409	Kers	Pterocelastrus tricuspidatus	CELASTRACEAE	Cherrywood, Candlewood	Kershout
410		Mystroxylon aethiopicum	CELASTRACEAE	Kooboo-berry	Koeboebessie
413	Sy	Robsonodendron eucleiforme	CELASTRACEAE	White Silky Bark	Witsybas
414	Bsaf	Cassine peragua subsp.peragua	CELASTRACEAE	False Saffron	Bastersaffraan
415	Saf	Elaeodendron croceum	CELASTRACEAE	Common Saffron	Gewone Saffraan
416		Hartogiella schinoides	CELASTRACEAE	Spoonwood	Lepelhout
420		Cassinopsis ilicifolia	ICACINACEAE	Lemon Thorn	Lemoentjiedoring
422	WP	Apodytes dimidiata subsp dimidiata	ICACINACEAE	White Pear	Witpeer
423		Allophylus decipiens	SAPINDACEAE	False Currant	Bastertaaibos
437		Dodonaea angustifolia	SAPINDACEAE	Sand Olive	Sandolien
438		Hippobromus pauciflorus	SAPINDACEAE	False Horsewood	Basterperdepis
451	KD	Scutia myrtina	RHAMNACEAE	Cat-thorn	Katdoring
452	BB	Rhamnus prinoides	RHAMNACEAE	Dogwood	Blinkblaar
457		Sparrmannia africana	TILIACEAE	Cape Stock-rose	Kaapse Stokroos
463		Grewia occidentalis	TILIACEAE	Cross-berry	Kruisbessie
479	RH	Ochna arborea	OCHNACEAE	Cape Plane	Kaapse Rooihout
479.1		Ochna serrulata	OCHNACEAE	Small-leaved Plane	Fynblaarrooihout
494	VRH	Kiggelaria africana	FLACOURTIACEAE	Wild Peach	Vaderlandsrooihout, Wildeperske
498	RP	Scolopia mundii	FLACOURTIACEAE	Red Pear	Rooipeer
499	DP	Scolopia zeyheri	FLACOURTIACEAE	Thorn Pear	Doringpeer, Wolwedoring
500	WMB	Trimeria grandifolia	FLACOURTIACEAE	Wild Mulberry	Wildemoerbei
509		Dovyalis rhamnoides	FLACOURTIACEAE	Common Sourberry	Gewone Suurbessie
513	HP	Olinia ventosa	OLINIACEAE	Hard Pear	Hardepeer
520		Passerina falcifolia	THYMELAEACEAE	Outeniqua Gonna	Outeniekwagonna
565	BKS	Schefflera umbellifera	ARALIACEAE	False Cabbage Tree	Basterkiepersol
568		Heteromorpha trifoliata	APIACEAE	Parsley Tree	Wildepieterseliebos
570	Ass	Curtisia dentata	CORNACEAE	Assegai	Assegaai
578	BH	Rapanea melanophloeos	MYRSINACEAE	Cape Beech	Boekenhout
579	WMH	Sideroxylon inerme	SAPOTACEAE	White Milkwood	Witmelkhout
599		Euclea racemosa	EBENACEAE	Sea Guarri	Seeghwarrie
600		Euclea schimperi var.schimperi	EBENACEAE	Bush Guarri	Bosghwarrie
601		Euclea undulata var.undulata	EBENACEAE	Common Guarri	Gewone Ghwarrie
603	Tol	Diospyros dichrophylla	EBENACEAE	Monkey Plum, Common star-apple	Tolbos, Gewone sterappel
603.1		Diospyros glabra	EBENACEAE	Blueberry Bush	Bloubessiebos
611	Btol	Diospyros whyteana	EBENACEAE	Bladder nut	Bostolbos
615	FYH	Chionanthus foveolata subsp.foveolata	OLEACEAE	Common Pock Ironwood	Fynblaarysterhout
615.1		Chionanthus foveolata subsp.tomentellus	OLEACEAE	Cape Pock Ironwood	Kaapse Pokysterhout

617		Olea europaea subsp.africana	OLEACEAE	Wild Olive	Olienhout
618	YH	Olea capensis subsp macrocarpa	OLEACEAE	Ironwood	Ysterhout
619	BYH	Olea capensis subsp capensis	OLEACEAE	False Ironwood	Basterysterhout
619.1		Olea exasperata	OLEACEAE	Dune Olive	Duine-olienhout
622.1		Azima tetracantha	SALVADORACEAE	Needle Bush	Speldedoring
624		Strychnos decussata	LOGANIACEAE	Cape Teak	Kaapse Klaat
634	V	Nuxia floribunda	LOGANIACEAE	Forest Elder	Bosvlier
636		Buddleja saligna	LOGANIACEAE	False Olive	Witolienhout
637	Salie	Buddleja salvifolia	LOGANIACEAE	Sagewood	Saliehout
639		Acokanthera oppositifolia	APOCYNACEAE	Common Poison-bush	Gewone Gifboom
641	Kam	Gonioma kamassi	APOCYNACEAE	Kamassi	Kamassie
670	N	Halleria lucida	SCROPHULARIACEAE	Tree Fuchsia	Notsung
688	WG	Burchellia bubalina	RUBIACEAE	Wild Pomegranate	Wildegranaat
693	WKP	Rothmannia capensis	RUBIACEAE	Wild Gardenia	Wildekatjiepiering
708	BD	Canthium inerme	RUBIACEAE	Common Turkey-berry	Gewone Bokdrol
710	KE	Canthium mundianum	RUBIACEAE	Rock Alder	Klipels
711	Kw	Psydrax obovata subsp obovata	RUBIACEAE	Quar	Kwar
723		Psychotria capensis	RUBIACEAE	Black Bird-berry	Swartvoëlbessie
726	Malb	Brachylaena glabra	ASTERACEAE	Malabar Tree	Malbaar
729		Brachylaena neriifolia	ASTERACEAE	Water White Alder	Waterwitels
733		Tarchonanthus camphoratus	ASTERACEAE	Wild Camphor Bush	Wildekanferbos