Application of a stem number guide curve for sustainable harvest control in the dry woodland savannah of Northen Namibia

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Research Note

Application of a Stem Number Guide Curve for sustainable harvest control in the dry woodland Savanna of northern Namibia

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SYNOPSIS

The savanna woodlands of north-eastern Namibia are a significant source of essential resources for the rural population. Thus far, however, there is little or no growth data available to predict future timber supplies and current yield regulation is limited to the issuing of harvesting permits based on the assessment of available tree sizes, rather than a tree population as a whole. This paper presents the negative exponential function for the development of a guide curve. The curve defines an optimum stand structure based on desired timber yields for specific tree sizes, the intrinsic mortality rates of individual species and the total desirable stocking of a stand. The application of the approach is assessed using the size class distributions of two prominent tree species of the Kanovlei area in north-eastern Namibia. While the function models the development of the populations of the species well, timber and non-timber trees will need to be modelled separately. In the coming years it will be an important priority to establish a system of sample plots to obtain growth data that may support or augment the system.

Keywords: Savanna woodlands, stem number, negative exponential function, guide curve.

INTRODUCTION

The dry woodland savanna of northern-eastern Namibia represents an important resource for the local population. Not only do the woodlands provide land for grazing, food, medicine and firewood, but also form the primary source of wood for the building of traditional homes, for fencing and for the carving industry (Namibia Forestry Strategic Plan 1996).

During 1990 a total sawlog volume of 5700m^3 was harvested to produce approximately 3100m^3 of sawn wood (Ollikainen 1992). Charcoal is not produced.

While the report by Ollikainen (1992) does not cover the consumption of wood by the carving industry, the volumes of timber used by this sector are substantial. It is doubtful that current levels of exploitation from the woodlands are sustainable, although no data is available to validate this.

However, comparison of casual observations made in 1994 and 2004 indicate that the carving industry now includes species such as *Pterocarpus angolensis, Guibourtia coleosperma, Schinziophyton rautanenii, Baikiaea plurijuga* and some *Combretum* species, while in the past, *P. angolensis* was the species almost exclusively used.

In the past, a number of concessions had been granted for the exploitation of *P. angolensis* and *B. plurijuga*. Concession holders were allocated a given area in which they were allowed to cut any *P. angolensis* or *B. plurijuga* tree with a dbh larger than 45cm or 32cm respectively. The diameter limits are prescribed in the forestry legislation.

At present all timber-harvesting concessions have been discontinued based on a general perception of overutilization rather than specific data. Permits are, however, still issued for small-scale exploitation of *P. angolensis* using the 45cm minimum dbh limit, but restricting permits to 5 trees per applicant per year. Granting or rejecting a permit application is generally at the discretion of the inspecting officer who primarily assesses the availability of the requested trees and their sizes, rather than the tree population as a whole.

Although *Burkea africana* is not harvested commercially it is frequently used for the construction of traditional houses, fencing posts or firewood, with no minimum dbh being specified.

Currently there is little or no growth data available in Namibia on which to base a more appropriate yield regulation system (Hangula 1999). This lack of information has particularly serious implications for the more popular species, such as *P. angolensis,* *B. africana* and *B. plurijuga*.

Using published figures from other areas is not a reliable solution. Consider for example that *P. angolensis* is said to have a diameter growth of approximately 0.5mm per year in Tanzania (Schwartz ET AL. 2002), 2.6-3.9mm per year in Zimbabwe (Stahle ET AL. 1999) and 2.0-7.5mm in South Africa (Shackleton 2002) (See also Vermeulen 1990 for growth data). All these areas have a higher rainfall and can therefore expect higher growth rates than Namibia as diameter growth seems to be linked to rainfall (Stahle ET AL. 1999). Also, none of the authors specify stand density. This parameter is important, however, since *P. angolensis* is sensitive to competition.

Optimally, a system is required that uses age or size structures to determine the quantity of timber that may be extracted from a given age or size class within a particular forest over a specified period of time (see Von Gadow and Bredenkamp 1992).

In Namibia a yield regulation system needs to address or cope with a number of additional issues. Some of these were already identified by Seydack et al (1990) for consideration in the Knysna forests of South Africa, and include the following:

- The different woodland species have different recruitment strategies and requirements that need to be considered.
- Trees are cut to serve a variety of uses. The required diameters differ between species and uses.
- The cutting of trees may not kill the tree but reduce it to a coppicing stump that has the potential to develop into an adult tree.
- The woodlands need to maintain a continuous cover with the removed trees replaced by natural regeneration as far as possible to minimize cost of establishment.
- The system needs to be simple to implement in the field. Namibia is in the process of establishing a series of community forests that are to be managed by members of the communities. While management planning, including yield regulation, is done with the assistance of the forestry authorities the implementation of management is left to the communities.

Seydack ET AL. (1990) and Seydack (1995) describe criteria and implementation of a mortality pre-emption approach to the calculation of harvesting levels and the selection of individual timber trees in the Knysna forests. Here, harvesting levels are established as a function of the ingrowth. While the system accommodates a number of the difficulties named above, it cannot be implemented here due to the lack of the necessary data.

The above restrictions and issues may also be addressed by the application of a stem-number guide curve that specifies the distribution of trees among specific size classes for an uneven-aged forest or woodland, and based either on a prerequisite stocking or stand basal area. This distribution represents an idealized stand structure in terms of stem numbers, basal area or volume (Cancino and Von Gadow 2002), and is affected by the mix of timber size classes that are ultimately desired, as well as the natural mortality of trees within the stand.

Decisions on exploitation may be made by comparing the actual number of stems within the various size classes with the ideal distribution; the trees that are in excess within the size classes may be removed (Von Gadow and Puumalainen 2000). The selection of individual trees may then follow the mortality pre-emption approach similar to that described by Seydack (1995).

The most prominent approach to model stand development in the literature uses a Markow type model similar to the Gentan model described by Suzuki (1983). The model multiplies the size or age class distribution with a set of survival probabilities to establish distribution for the next time interval. The approach permits the modeller to exercise control over the development of stems from one age or size class to the next, independently of all other classes.

Desmet ET AL. (1996) attempted to use the stable state distribution that results from numerous iterations of such a model to guide harvesting regulation but found the model to be inadequate. Schwartz ET AL. (2002) had a similar lack of success with their model for a Tanzanian population. Childes (1984) investigated the application of the model using growth stages of *B. plurijuga* rather than a size class distribution, but was not able to generate satisfactory results.

A considerable drawback of the technique is the large amount of data required for the construction of the transition matrix. This is complicated by the fact that growth rates may vary due to changes in environmental conditions, age or size of trees. Strictly speaking, therefore, a series of transition matrixes would be required to represent multiple growing conditions, and would require significantly greater amounts of data.

A further difficulty rests with the necessity to estimate fecundity within each age class. Fruit and seed production are, however, often linked to rainfall, tree size or fire history. (see Rutherford 1982, Vermeulen 1990, Shackleton 2002, Graz 2002, and Wilson and Witkowski 2003).

This paper investigates the potential of the negative exponential function for the development of a stem number guide curve in order to determine sustainable harvesting quotas.

THE INVERSE EXPONENTIAL FUNCTION

The inverse exponential function follows an inverse-J shape and may be used to model the survival of trees within a given management unit or arbitrary population through any series of consecutive size or age classes (Cancino and Von Gadow, 2002). The function models a consistent decline of a large number of small diameter trees as they progress through a series of size classes over time. This decline is assumed to be a result of natural mortality so that an allowable cut may be determined as the number of trees in excess of the modelled class minimum. The negative exponential curve has the general form:

$$N_i = k_0 e^{-k_1 d_i}\ , \qquad (1)$$

where N_i is the number of trees in size class *i*, k_0 is the intercept with the y-axis, k_1 determines the rate of change, and d_i is the diameter class midpoint of class *i*. Note that here *i* is followed in reverse, i.e. from high value to 1, in contrast to the more conventional approach regarding index values. This reversal simplifies the calculation of the final distribution, as will become more evident later. The distribution will therefore increase from the larger size classes towards the smaller diameters at a constant rate, *q*, that may be calculated as:

$$q = N_{i+1} / N_i \qquad (2)$$

Since *i* is assumed to progress from the largest to smallest diameter class, N_{i+1} represents the number of trees in the next smaller dbh class after N_i. The inverse of *q*, ie. q^{-1} represents the survival of trees from one size class to the next larger one.

To illustrate this, consider the following. In a stand 75% of trees survive from a size-class to the next larger one. Therefore q^{-1}=0.75 and *q*=1.333. Since the value of *q* does not change it is possible to determine a theoretical distribution of dbh values, given an initial number of trees in the largest size class. A value of *q*>1 means that stem numbers increase between successive size classes. A value of *q*=1 implies that no change takes place from one size class to the next, similar to the normal forest described by Brasnett (1953). A value of *q* < 1 may be obtained, but would cause a distribution where frequencies are steadily increasing as diameters increase.

Figure 1 depicts the dbh-class distributions determined using two different values of *q*. The first distribution, **Figure 1a**, was obtained with *q*=1.2 while the second, **1b**, uses *q*=1.3, with the other parameters unchanged. From the figure it is evident that the distribution is quite sensitive to the magnitude of *q*.

The diameter distribution is, however, not only determined by the value of *q*, but also by the number of diameter classes that comprise the distribution, which depends on the diameter class width, *h*. The relationship between *q* and *h* is given by:

$$q = e^{k_1 h} \qquad (3)$$

It is important to maintain this relationship in order to retain a consistent stocking rate for different diameter-class distributions obtained from different values of *q* or *h*. (for an explicit derivation see Cancino and Von Gadow 2002).

In order to determine a specific number of trees in the largest diameter class, N_1, Cancino and Von Gadow (2002) identify a maximum diameter, *D*, beyond which trees would not develop. Given N_1, we may calculate the number of trees in any size class, *i*, as:

$$N_i = N_1 \cdot q^{i-1}\text{, where } 1 \le i \le (D/h) \qquad (4)$$

Although fractions may be inserted into **equation (4)** *h* should be chosen in such a way that an integer value is obtained to ease the interpretation of the results.

The diameter class distribution obtained with **equation (4)** would remain sustainable if no more than the excess trees in each of the diameter classes are cut, and that regeneration is consistent. The value of *q* may be chosen at the inherent survival rate of the species, or higher.

For example, by specifying that 20 trees need to survive to the maximum diameter of 50cm, using a class width of 5cm and a rate of change of *q*=1.25 we

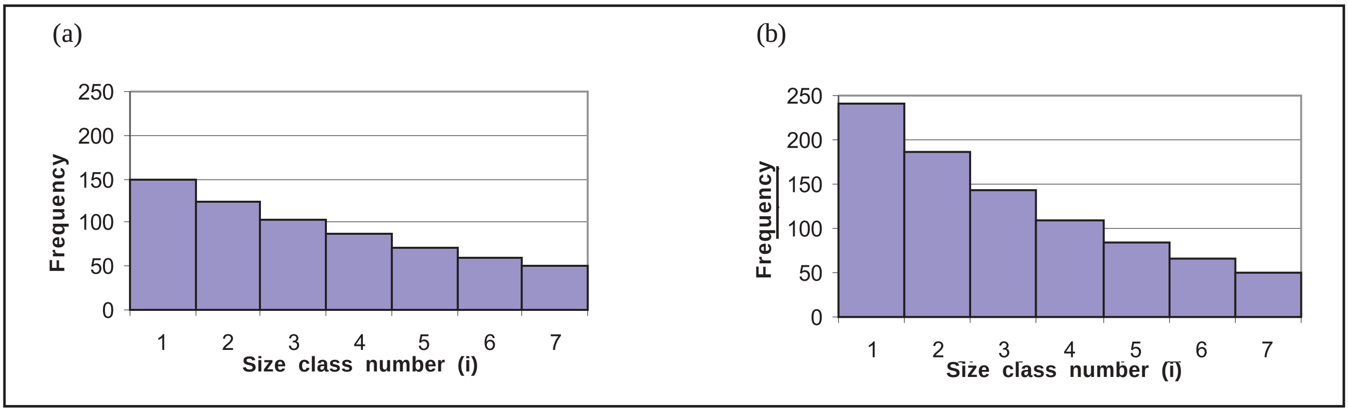

FIGURE 1. The graphs show the hypothetical dbh- class distribution of two stands, with (a) q=1.2; and (b) q=1.3

obtain the diameter class distribution provided in **Figure 2**.

As an alternative to stipulating a final number of trees in the largest diameter class, it is possible to specify a total growing stock (in terms of stem numbers), *G*, or total basal area, *B*, for a specific stand.

Given values for *q* and *G* **equation (5)** may be used to determine the trees required in diameter class 1, while the remainder of the diameter class distribution would be calculated using **equation (4)**.

(5)

Using a stand basal area, *B*, that is based on the dbh-class midpoints, then:

$$B = k_2 \sum_{i=1}^{n} N_i \cdot d_i^{\,2} \ , \tag{6}$$

where k_2=ð/40000.[1]

Replacing N_i with **equation (4)** and solving for N_1 we obtain:

$$N_1 = \frac{B}{k_3} \ , \tag{7}$$

where:

$$k_3 = k_2 \sum_{i=1}^{n} q^{(i-1)} \cdot d_i^{\,2} \tag{8}$$

(See Cancino and Von Gadow (2002) for a full proof of their equations)

The parameter k_3 is also affected by the number of dbh-classes and plays a key role in the calculation of the distribution. k_3 must therefore also be recalculated if *h* is changed.

When dbh-class distributions are determined for a given stand basal area, but different values of *h*, it is important to note that different stocking rates may nevertheless be calculated. This is because the basal area is determined using the class midpoint only, disregarding the variations of diameters within each class. This difference is not observed when the distribution requires a specific total number of stems.

Where the function is used to target larger or smaller diameters it is tempting to manipulate the value of *q*. The parameter must, however, not only be considered in terms of the mathematical ease with which the guide curve can be manipulated, but also in terms of the biological interpretation and subsequent implications. While it is always permissible to use a value of *q* higher than that resulting from the intrinsic mortality rate of a species, the value may not be set lower since this would imply improved survival. This can, of course, not be guaranteed.

It is more appropriate to consider the manipulation of *D* and *G* or *B*, when calculating the guide curve. A reduction in the residual minimum growing stock *D* and *B* for example provides for a higher allowable cut in the smaller dbh-classes for a given survival and regeneration rate, as shown in **Figure 3**.

When determining a relatively small maximum diameter it must be remembered that a certain number of seed trees / habitat trees must remain. The minimum number of trees needed differs between species and needs to be established in terms of seed production per tree and the viability of the seed.

Dbh class	**Stem numbers**
1	149
2	119
3	95
4	76
5	61
6	49
7	39
8	31
9	25
10	20
Total	664

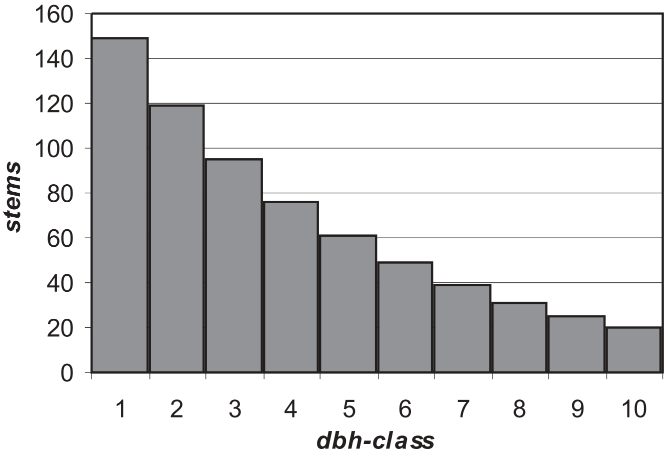

FIGURE 2. The distribution of trees in 10 dbh-classes that represent a sustainable population given the maximum diameter size, the number of diameter classes and the annual rate of reduction.

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[1] k_2 converts the diameter in cm to an equivalent basal area in m^2 per hectare.

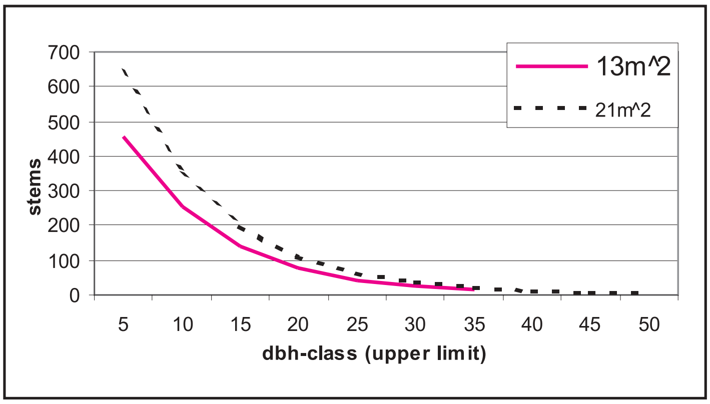

FIGURE 3. Guide curves for a tree species using $B=21m^2$ *with* $D=50cm$*, and* $B=13\ m^2$ *with* $D=35cm$*. The value of* $q=1.8$ *remained constant.*

APPLICATION AND INTERPRETATION

Before a stem number guide curve is implemented it is necessary to determine whether or not the model adequately describes the stand structure or its development.

To do so let us consider the dbh-class distribution presented in **Figure 4**. The figure depicts the diameter distribution of a savanna woodland stand of 11.8ha at Kanovlei in northeastern Namibia, with the line graph indicating the negative exponential curve using $N_1=10$ and $q=1.63$ in **equation (4)**.

The trees with a dbh of less than 15cm comprise of 64% regeneration of *P. angolensis*, *B. africana* and *S. rautanenii*, and a further 33% of species of the genus *Combretum* that does not contribute to utilizable timber in this region.

Although it is clear that there is a very large difference in actual and expected stem numbers in the second and third dbh-classes, a Chi-square analysis indicates that the negative exponential curve nevertheless describes the distribution well (p = 0.188) if these two classes are not considered.

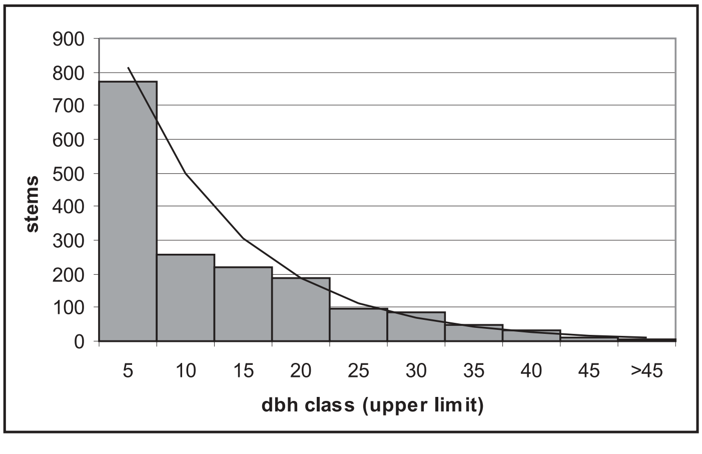

FIGURE 4. Diameter-class distribution of woody plants in a woodland stand near Kanovlei, Namibia (bars), and the hypothetical distribution with $N_1=10$*, and* $q=1.63$*.*

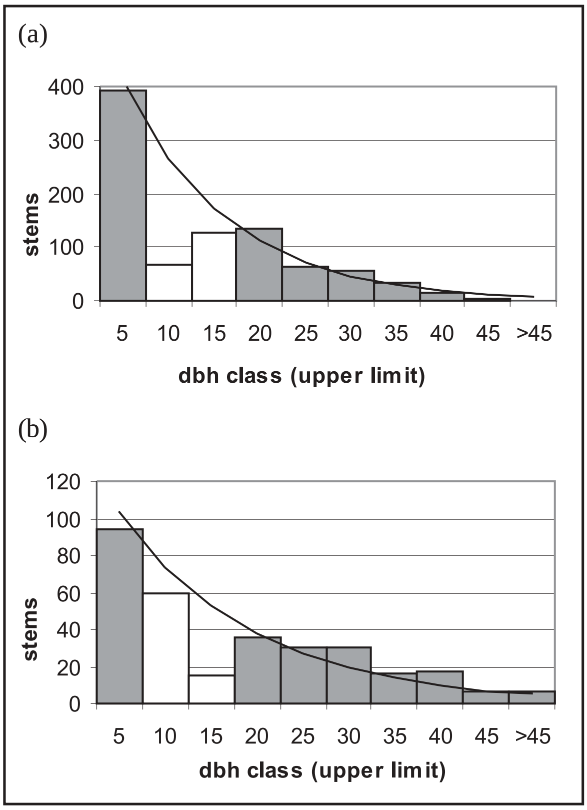

FIGURE 5. The dbh-class distributions (bars) and the best fitting negative exponential curves of (a) Burkea africana, with $q=1.55$ *(p = 0.006); and (b) Pterocarpus angolensis , with* $q=1.31$ *(p = 0.749) ignoring the poor fit of classes two and three in each case.*

Since not all species are used in the same way, and because the may have different ecological profiles that result in different population structures, it is necessary to consider the application of the model for individual species. **Figure 5** shows the diameter distribution of *B. africana* (**5a**) and *P. angolensis* (**5b**) within the above stand. The distribution of *P. angolensis* in **Figure 5a** is very similar to that found by Schackleton (2002) at Bushbuckridge Nature Reserve in South Africa.

The figure shows that the model describes the *P. angolensis* diameter distribution well (p=0.749), again ignoring the second and third size classes. *B. africana*, on the other hand, is very poorly explained (p=0.006) under the same conditions. The description of the distribution of *B. africana* is significantly improved (p=0.135) if only the seven size classes larger than 20cm are used. Consider that a nearby community utilizes the smaller size classes for firewood and building material, as these trees are easier to handle than larger trunks. This was evident from a number of stumps observed in the field. In addition, Wilson and Witkowski (2003) determined that the species only produces a permanent shoot once its dbh exceeds 13cm.

The stems 'missing' from age classes two and three may therefore have accumulated in the smallest age class.

IMPLEMENTATION OF THE CURVE

In view of the above, the inverse exponential curve can be used to describe stand development in a way that mimics natural mortality patterns, despite the difficulties concerning individual size classes. Given that environmental conditions remain favourable for regeneration, and mortality rates remain the same, those trees in excess of the modelled minimum number of trees may be harvested. The parameters of the guide curve must remain such, however, that the curve does not permit harvesting in excess of the natural mortality rate of the tree population.

As the required timber sizes for the two above species differ, they will require different curves to describe mortality rates and residual stocking. Since mostly the smaller tree diameters of *B. africana* are used, the guide curve for this species, for example, needs to target the smaller size classes. On the other hand that of *P. angolensis* must provide for a greater number of larger trees.

This concept must be developed further, however. A number of species do not contribute to timber production but rather serve different purposes. Trees or species may therefore be grouped as follows:

Class I: Principal timber species

> The class includes all the reproductive stages of the principal timber species in the form of seedlings, suffrutex or coppice, as well as saplings, immature and mature trees. While some species considered in this class may also have medicinal uses, they are primarily timber producers.

Class II: Non-timber trees

> Trees that produce edible fruit, browse for domestic stock or those which provide other products used for medicinal purposes, but are not harvested for their timber.

Class III: Dead trees

> Trees that have died through fire, fungal attack or other cause and are unable to coppice.

Trees within *class I* should be modelled separately for the individual species.

The trees in the data set falling into *class II* also show the inverse-J development curve, as shown in **Figure 6**. While the contribution of the non-timber trees seems very low in this stand, unpublished data shows that their number may exceed the timber trees by far.

Despite the predictability of tree mortality itself, the number of dead trees at a given time cannot always be predetermined accurately, as these trees may quickly be reduced to ashes once they have actually fallen over; decomposition is slow.

Although the mathematics themselves are comparatively simple, some difficulty may be experienced with the estimation of the required parameters. This is particularly the case in the light of the absence of background information.

Perhaps the most difficult parameter to estimate is q, since it must reflect inherent mortality rates as well as management goals. This is not only the case under Namibian conditions, but was identified by Von Gadow and Puumalainen (2000) as a general concern. There is no hard-and-fast rule that can be applied to determine q. However, the two authors also show that there is a range of parameters may

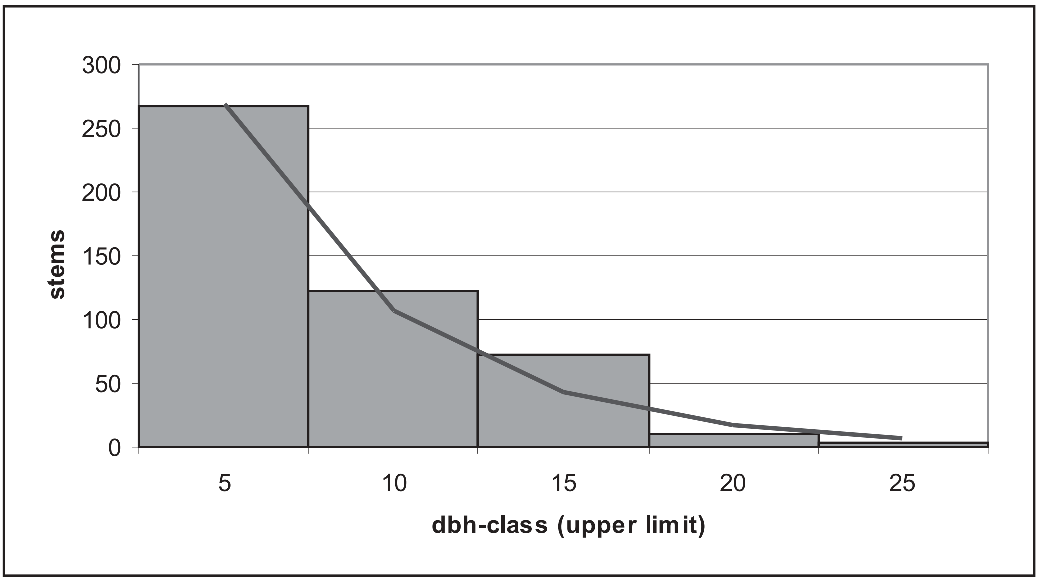

FIGURE 6. Diameter class distribution of non-timber trees in Kanovlei and the stem-number guide curve based on $q=2.5$ and $B= 3$.

produce sustainable diameter distributions. This permits some leeway in the choice of the parameters, although they should remain within the range of those obtained from inventory data.

It is necessary to keep in mind that mortality in the small size classes is very high, particularly as a result of fire. Although larger trees have a higher fire tolerance, they may also be damaged or killed, particularly if the bark of the trees has been damaged either by animals (see Yeaton 1988, Shackleton 2002) or growth stresses (Graz 2003).

A relatively high value of q may therefore have to be chosen to make allowance for the fast initial decline. It should be borne in mind that the structure of the tree population is a reflection of the historical influences that have enacted on it, as well as by inherent properties of the species such as frequency and success of recruitment events; q is therefore reflected in the current structures evaluated above. At the same time, the variability of the factors that influence the magnitude of q dictate that this parameter is periodically reassessed.

During the initial phases of implementation smaller and therefore a greater number of diameter classes can be used. This will provide managers with a more detailed insight into population structure and development. If diameter classes are wide, problems within a class may be masked.

Various enumerations indicate that stem numbers of trees larger than 5cm dbh amount to approximately 100 to 200 stems per hectare (Korhonen et al 1997a, Korhonen et al 1997b, unpublished data). While these figures may seem very low, they reflect the carrying capacity of the site, in terms of available water and nutrients, and should be used as guidelines.

The spatial distribution of the various size classes was not considered here. *P. angolensis*, for instance, frequently occurs in even sized stands (Graz 2004) which may exclude some size classes entirely from the management unit. In such cases the exploitation of the adjoining classes will need to be restricted to compensate for such gaps and to ensure sufficient numbers of habitat trees.

CONCLUSION

The stem number guide curve described above serves the same purpose as the normal forest concept for plantation forestry as already described by Brasnett (1953). Both approaches describe an ideal structure that managers may strive towards but will never attain.

The negative exponential function adequately describes the natural mortality patterns of the species considered here. It may therefore be used to define a dbh-class distribution that is sustainable given current mortality and recruitment rates.

In the almost total absence of growth data in Namibia, the stem number guide curve provides a means of establishing periodic harvesting levels that will ensure sustainability. Implementation will require, however, that conditions are suitable for the regeneration of the individual species, and may require the maintenance of a disturbance regime.

In order to augment the implementation of the system, it is necessary to obtain more detailed growth data. As yet no system of permanent sample plots has been established in the woodland areas, although such a system is currently under development by the Directorate of Forestry, based on an earlier fire trial (Geldenhuys 1977).

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