DENSITY MANAGEMENT DIAGRAM-THEIR CONSTRUCTION AND USE IN STAND MANAGEMENT

SEMINAR REPORT
(SA. 651 Silviculture seminar)

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DECLARATION

I, Sureshkumar, S. hereby declare that this seminar report entitled "Density management diagram- their construction and use in stand management" has been prepared independently by myself after going through the references cited herein.

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CONTENTS

1. INTRODUCTION

Density management is the manipulation and control of growing stock to achieve specific management objectives. While the actual control of growing stock is relatively easy to achieve, through initial spacing and intermediate cutting, the determination of appropriate levels of growing stock at the stand level is a complex process involving biological, technological and economic factors specific to a particular management situation (Davis, 1966). Density management through manipulation of stand density with thinning is the single most influential activity a silviculturist can perform between successive regeneration periods. The control of density levels in a stand has tremendous impact on that stand's structure, productivity and ability to produce a variety of resources.

Rational density management must start with fairly specific management objectives and these objectives must then be translated into stand-level prescriptions. (Long and Mc Carter, 1985). There are a variety of tools available to design density management regimes. Each of these tools has a place in the planning and execution of density management regimes. Graphical models represented by various types of stocking control charts and density management diagrams are of special importance in stand density management.

Density management diagrams are the most comprehensive of these models which can effectively translate general management objectives into stand specific thinning prescriptions. They are simple stand average models which graphically characterize yield, density and mortality at various stages of stand development (Newton and Weetman, 1994). The apparent simplicity of DMD's belies their ability to display the complex dimensional relationship of developing stands. Some of the fundamental concepts of growth, competetion, yield and stand density are applied in the construction and use of density management diagrams. A clear understanding of these basic concepts is essential for the evaluation of density management diagrams.

2. GROWTH OF A POPULATION OF COMPETING PLANTS

Although different members of a plant population may be at very different stages of growth the manner of accumulation of biomass through time by a population often closely parallels that for a single plant. The growth curve is sigmoid. But eventually as their sizes increase, plants begin to interfere with each others growth by competing for the resources - leading to competetion - and the maximum potential growth rate will not be achieved by the population.

Under competitive conditions the form or size of a plant may be modified without leading to death of the plant - these modifications are termed as plastic responses. As the population continues to grow , a point is reached when habitat cannot support more biomass and any further growth can occur only at the expense of some biomass already present. Thus parts of plants or even whole plants will die. These process of growth , competetion and death are results of several characteristic features and growth of individuals in the population.

2.1. Competetion - Density (C-D) effect

Consider a set of plant population, each growing under same habitat conditions but starting growth at a different initial density . After a certain period of growth, the populations begin to exhibit plasticity as a response to the onset of competetion. At this stage, there exists a relation between mean plant weight and density of survivors (Kira *et al.*, 1953). The generalized equation is

$$w = kd^{-a} \quad \text{----------------(1)}$$

Where w = mean plant weight

d = plant density

a and k are constants

This equation can be represented linearly by plotting on double log. axes and expressed as

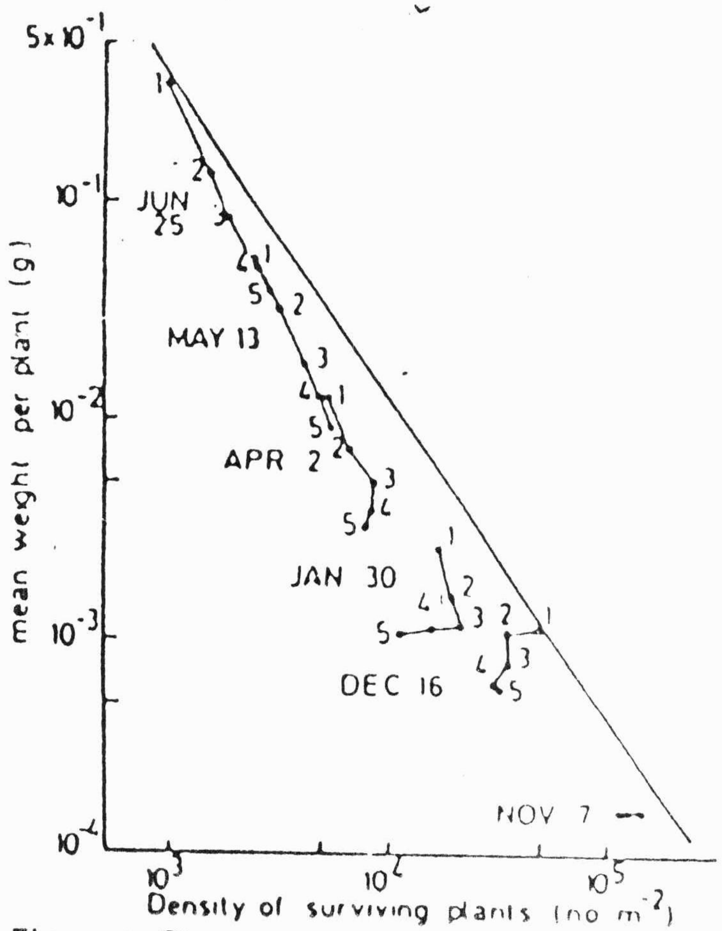


Figure 1. Changes in number of survivors and mean plant weight through time in monocultures of *Erigeron canadensis*. Numbers 1–5 represent data collected from plots of different fertility. 1 = highest fertility, 5 = lowest fertility. Separate harvests are indicated by their dates and the results from a single harvest date are joined by solid lines. The straight line has a gradient of − 3.2. Re-drawn and adapted from Yoda et al. (1963).

$$\text{Log } w = \text{Log } K - a \log d \quad \text{-------(2)}$$

(Figure 1 gives the relationship)

The eq (1) is termed the competetion density equation (C -D equation) and the constant 'a' the C-D index. Through time the value of 'a' increases; at the early stages mean plant weight is independent of density. Given sufficiently intense competetion the C-D index eventually rises to 1, which indicates complete compensation for higher density by lower mean weight, resulting in same total biomass for all populations.

2. Reciprocal equations

A major draw back in describing population weight - density relationships with C-D equation is that it assumes that the density at which competetion becomes visible is clearly defined. But this is not true for high density ranges , over which competetion exerts an ever - greater effect. Hence Shinozaki and Kira (1956) proposed a suitable equation for the curve.

$$\frac{1}{W} = Ad + B \quad \text{--------------- (3)}$$

Where A and B are constants. This equation was termed th reciprocal equation of the C-D effect.

2.3. The -3/2 power law

As each population continues to grow, the capacity of some individuals to absorb competetion by plastic responses will be exceeded. At this point and further, plasticity and mortality occur simultaneously.

Over this period - in which density dependent mortality occur - the equation relating to the points on the graph is

$$w = kd^{-3/2} \qquad \text{--------------(4)}$$

or

$$\text{Log } w = \text{Log } K - 1.5 \log d$$

Eq (4) is termed the -3/2 power law (Yoda *et al.*, 1963) where k is a constant. It's gradient is approximately 56°C.

The limitation upon biomass accumulation represented by this gradient is a reaction against packing more biomass into a given volume. An explanation of the exponent was proposed by Yoda *et al.* (1963) based on some geometric models.

For fully occupied sites at any stage of development, the relationship between average ground area occupied by a plant (S) and the current density (plants per unit area) is inversely proportional.

$$S \alpha \frac{1}{d} \text{ ----------- } (5)$$

The average ground are occupied will be proportional to the square of a liner dimension of the plant (L) and weight (W) to the cube of the linear dimension

$$S \alpha L^2 \text{ ------- } (6)$$

$$W \alpha L^3 \text{ ------- } (7)$$

Thus the space occupied by the plant and weight is related as

$$S \alpha L^2 \alpha (L^3)^{2/3} \alpha w^{2/3}$$

$$\therefore 1/d \alpha W^{2/3}$$

$$W \alpha d^{-3/2}$$

$$W = kd^{-3/2} \text{ ------------- } (8)$$

The power constant in this relation can be determined only if two assumptions are valid Firstly - the restrictive assumptions of constant tree shape, i.e. all plants of a given species are geometrically similar, regardless of size and growing conditions.

Secondaly - the mortality occurs when the percentage cover of plants exceeds 100 % and operates to maintain 100 % cover. The area occupied by a plant and the density of survivors are related only if this assumption is valid.

Yoda and others transferred this relationship to monoculture tree stands to describe the weight density relationship in a population. The conditions that must be satisfied for them to apply are minimal. The population must have been growing for the same length of time and there should be no environmental gradients within or between the populations. Then the -3/2 power law was used to describe the weight density relationship in a population at different times as thinning proceeds and subsequently this line was referred as the maximum size density relationship.

Several ecologists examined the -3/2 power law proposed by Yoda and co-workers found that in pure even-aged stands there is a maximum population density dependent on the plants stage of development. In spite of differences in age, stage of growth, locality and micro habitat conditions a single line represents the plant size - density relation throughout the stands. In every instance the slope of the line was close to -1.5. The self thinning line defined by the -3/2 power law which inturn termed as maximum plant size refers to the maximum attainable value of the average plant size for a given stand condition and not to the maximum size of the individual trees within the stand.

The critical planting density decides the onset of mortality. For low initial planting densities there was no mortality but as initial density increased the density of surviving plants at a fixed time after sowing approached a fixed maximum

3. Yield density Relationships

Based on the above studies, the basic relationships between yield and density for any stage of stand development have been mathematically described with varying degrees of complexity and success. Willey and Heath (1969) found that reciprocal equations offer the best possibilities of being able to describe yield-density relationships accurately and meaningfully.

Eq(3) developed by Shinozaki and Kira (1956) is found to be the most realistic among all these equations. This equation starts with a logistic growth equation which defines plant weight as a function of age. Their approach incorporated the law of constant final yield formulated by Hozumi and others (1956). The law of constant final yield states that final (as time approaches infinity) yield per unit area (Y) is constant and independent of density.

$$W = Y/d \quad \text{----------} \quad (9)$$

Where

W = Final weight

Y = Yield per unit area

d = density

Similar to the reciprocal law of C-D effect, reciprocal equation of Y - D effect is also developed as

$$y = d/(Ad + B) \quad \text{-------------}(10)$$

3.1. Maximum size - Density relationship and the Reciprocal equation

Eq(10) describes mean plant weight as a function of density before substantial mortality occurs, where as the - 3/2 power law estimates max. mean plant weight as a function of density in stands where substantial mortality is occurring. This relationship is independent of initial stocking and stage of stand development. A trasnitional period exists between the stand being described by the two equations.

The less dense plots do not decrease in density over time as do the plots with high initial densities. Sufficient mortality occurs so that the points fall close to or below the self thinning line. Thus reciprocal yield law is applied to all stands, irrespective of whether competition -

induced mortality occur or not. Whereas occurrence of competetion - related mortality is limited to stands meeting certain size density criterion.

4. Designing a density management regime

In any approach to density management the managemental objectives are translated into specific target levels of growing stock. In principle the stand is allowed to grow to the targeted upper limit of growing stock and is thinned down to the lower limit. This process is repeated as many time as necessary (Long, 1985). Typically some modifications is needed to accommodate some aspect of the management objective.

The transmission of specific management objectives into appropriate upper and lower levels of growing stock is ofcourse, the key to and most difficult step in designing a density management regime, (Davis, 1966). Stand density based index of growing stock such as SDI greatly simplifies the process.

4.1. Stand Density Index (SDI)

The most generally effective indices of growing stock are those that combine some expression of mean size (weight, volume, height or DBH) and density (TPHA), (Curtis, 1970, 1971; Long and Smith , 1984). Most familiar of these indices is Reineke's (1933) stand density index - a predictable relationship between quadratic mean diameter and trees per unit area in dense stands.

Others - Mean volume density (Drew and Flewelling, 1977)
- Mean height density (Wilson, 1979)
- Relative density

All these indices are independent of site quality and stand age.

SDI is the No. of trees per hectare as if the quadratic mean diameter (DBH) were 25 cm. Given the actual tpha and DBH_q, SDI can be calculated (Daniel and Sterba, 1980).

$$SDI - tpha\ (DBH_q/25)^{1.6}$$

While the calculation of SDI is independent of species the, significance of SDI varies from one species to another. Hence SDI as percentage of the maximum is used.

For Eg:

Maximum	100 %
Lower limit and selfthinnig -	60 %
Lower limit of full site occupancy	35 %
Onset of competetion - (Crown closure)	25 %

The self thinning rule (discussed earlier) is the basis of various stand density indices, because it's independent of both stand age and site quality and hence provides an excellent basis from which an understanding of the competitive interactions between individuals in a population can be developed (Hutchings and Budd, 1981). A stand density that is deemed ideal in the context of a particular set of management objectives can be projected forward or backward to a different stage of stand development. Thus growth growing stock relations can be translated into density management prescriptions for stands of different ages and site quality.

The density management regimes and the upper and lower limits of growing stock, typically represent a compromise between maximization of volume production on an area basis and maximization of individual tree growth and size. This is because both aspects of growth cannot be simultaneously maximized. Langsaetar's (1941) Hypothesis illustrates the compromise between maximization of volume production on an area basis. (m^3/ha/yr) and maximization of individual tree growth and size. Figure 2 illustrates Langsaetar's (1941) Hypothesis.

For stands undergoing selfthinning, net growth of the stand will of course decline, where as, gross stand growth will baring stagnation remain on the plateau.

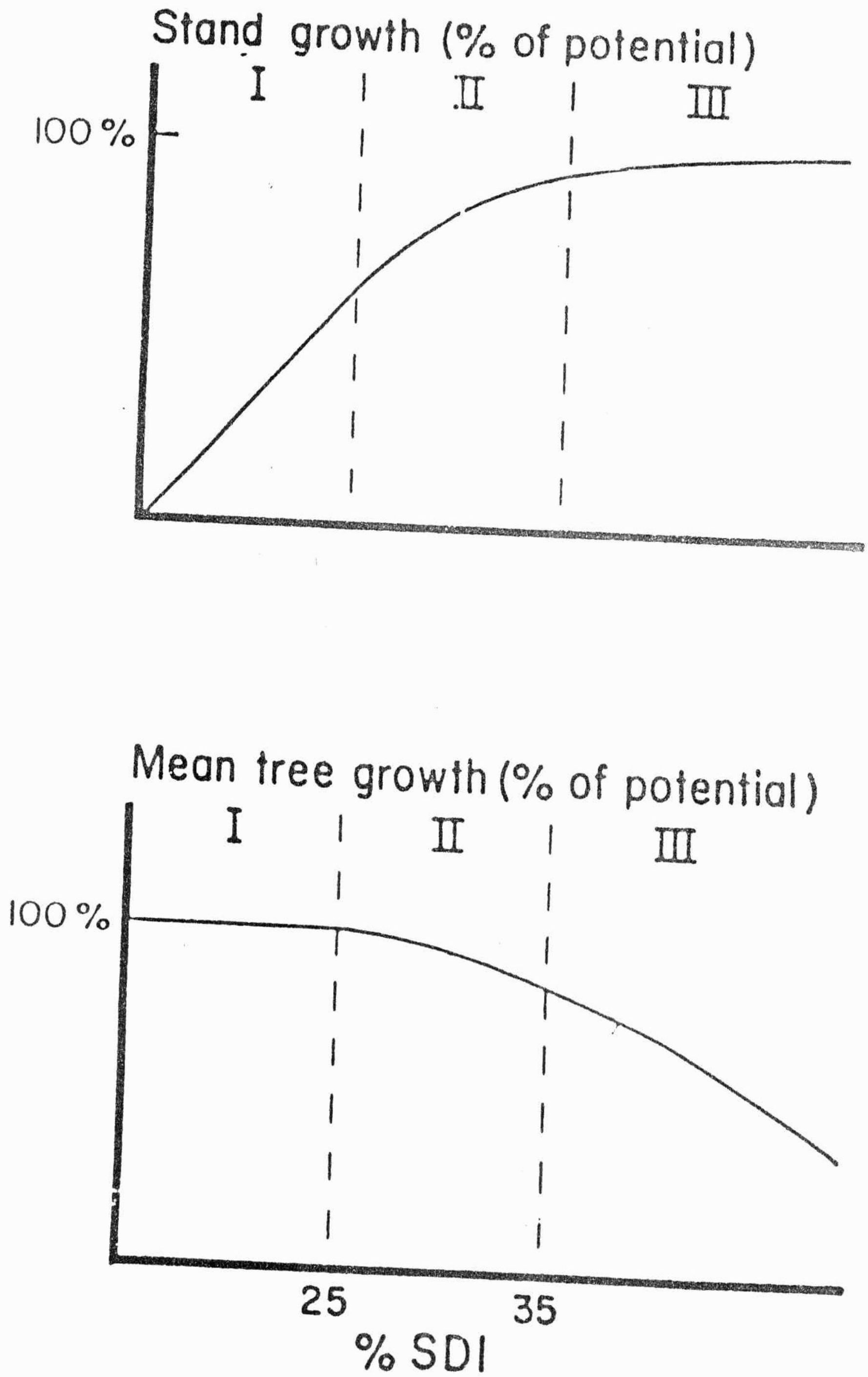


Figure 2. Current annual stand and individual tree growth as related to growing stock. % SDI is the actual SDI expressed as a percent of the species maximum SDI. Potential growth is dependent on species, site quality and stand age. (after Langsaeter 1941).

The nature of silvicultural trade - off between stand and individual tree growth is a direct consequence of the management objective.

For Eg: If the objective were to maximize total volume production without regard to individual tree size - the lower limits and upper limits are chosen in order to maintain the stand in zone III.

Where as if object is to maximize individual tree growth and size appropriate strategy is to maintain the stand within Zone I.

Basic principles in the process of fixing upper and lower limits of growing stock are:-

1. Stands growing below crown closure (R. D = 0.15 or SDI= 25) are not fully utilizing the site and density could be increased with out affecting mean tree growth.

2. Maximum tree size can be obtained by managing stands near or below the crown closure line.

3. Stands managed near the lower bound of imminent competetion mortality to a relative density of 0.4 or SDI 60 will have some what greater total stand growth but considerably smaller individual tree sizes than stands managed at lower densities.

4. Stands should not be allowed to enter the zone of inminent competetion mortality in order to avoid severe reduction in vigour and potential damage to trees.

5. Construction of density management diagram

The density management diagram is a graphical tool for relating stand density, tree size and stand yield. The way in which a diagram is formatted is largely a matter of personal preference where as the elements of a typical DMD depends on the management objective. The commonly used density management diagrams have mean tree volume or quadratic mean diameter on the Y-axis and stand density expressed as trees per hectare on the X - axis and the following relationships are superimposed.

1. Maximum size density relationship - already discussed

2. Imminent competetion - mortality.

The zone of imminent competetion mortality (Drew and Flewlling, 1977) is that array of stand conditions where competetion related mortality is likely to occur. The zone is bounded by two lines - the maximum size density relationship and a second line paralleling the first at lower densities for the mean tree size.

3. Crown closure

Often used to approximate the initiation of stand development as opposed to the growth of non competing trees.

4. Estimate of diameter and height.

This is used to better relate the diagram to actual stands, estimates of mean diameter and site height are related to the mean volume density conditions.

5. Relative density index.

A quantitative concept of growth as a function of density is stated. At densities below crown closure (R.D< 0.15) growth per unit area is proportional to density. At relative densities 0.15 to 0.40 growth per unit area increases with density, but growth per tree declines. At relative density between 0.40 and 0.55 growth per unit area in inaffected by density. For relative density greater than 0.55 gross growth is same as in the 0.40 to 0.55 region, but net growth may be considerably less than this, if substantial mortality has occurred. These conclusions are very similar to Langsaetar's hypothesis (cited by Smith, 1962).

The construction and interpretation of DMD require certain assumptions.

1. The locations of the maximum size density relationship is correct for all sites.

2. The lower limit of the zone of imminent competetion mortality is correct for all sites.

3. Individual tree growth is not related to stand density prior to crown closure.

4. The stand growth is at a maximum in the relative density 0.40 to 0.55 region.

5. Following thinning a stands growth potential temporarily falls below that indicated by its relative density. This fall down is assumed to be shortlived.

6. Use of Density management diagram

The principal value of the diagrams is their usefulness in planning for and evaluating the consequences of alterative density management regimes. Given reasonable assumptions about biological and economic constraints the diagrams facilitate the effective display of density management alternatives (Long, 1985). The diagrams may also be used to evaluate objectives other than timber production. They also have been used to evaluate wildlife habitat (Smith and Long, 1987).

7. Construction and use of DMD - A case study

Density managemnt diagrams have been developed for a number of Japenese and North American species (cited by Kumar *et al.*, 1995). With few exceptions (eg. Kikuzawa, 1982), Published diagrams represent temperate coniferous species. With the exception of teak, density management diagrom is not developed for any tropical species. Kumar and Kumar (1991) constructed a density management diagram for teak employing log-linear multiple regression models fitted to stand inventory data collected from three forest divisions of Kerala state.

7.1. Construction of the diagram

Quadratic mean diameter (Dq) and trees per hectare (TPH) were taken on the major axis. Growing stock level is represented by Reineke's (1933) stand density Index (SDI).

The maximum SDI represented in the data set is about 1200, which was assumed as a reasonable approximate of maximum size density releation for teak. Two additional sets of curves representing the top height (HTS) and total volume (VOL) were superimposed.

7.2. Use of the diagram

Relative density independent of species is expressed as a percent of species maximum SDI (% SDI). This expression assumes that a given range of % SDI corresponds to a particular stage of stand development or growth - growing stock relations for teak. (Kumar *et al*, 1995). These key relative densities are summarized in table - 1.

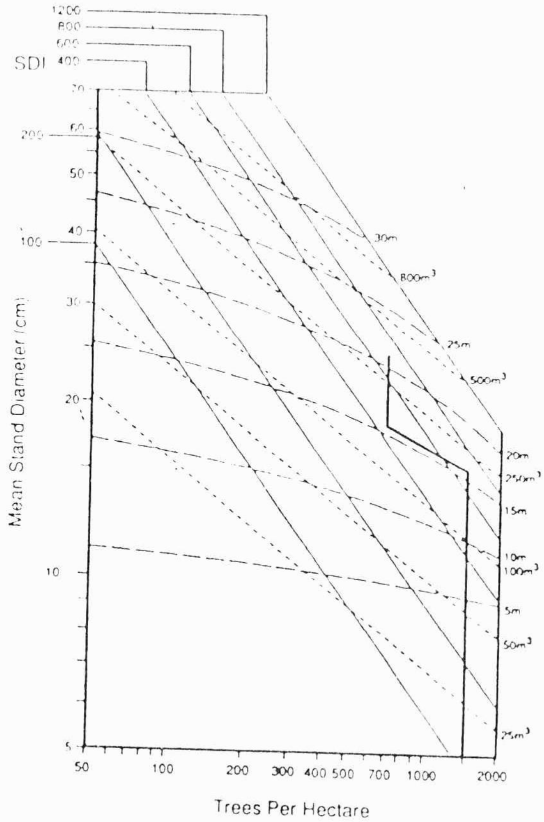
Since the selection of upper and lower limits of relative densities represent a silvicultural trade - off between maximum stand and maximum individual tree growth and vigour, two alternate density management regimes are used to illustrate the use of the teak density management diagram.

7.2.1. Pole production regime

The objective is to produce a large number of teak poles with a minimum commercially utilizable pole of about 10 cm and a target end-of-rotation Dq of 25 cm. Lower limit of SDI was 420 (35 % max SDI) and the upper limit 700 (60 % max SDI) to capture most of the stand growth potential of the site and to avoid self thinning respectively. With these assumptions a density management regime was drawn on the diagrom, starting at the end of the rotation and working backwards (Fig. 3). The pole production regime is summarised in Table 2.

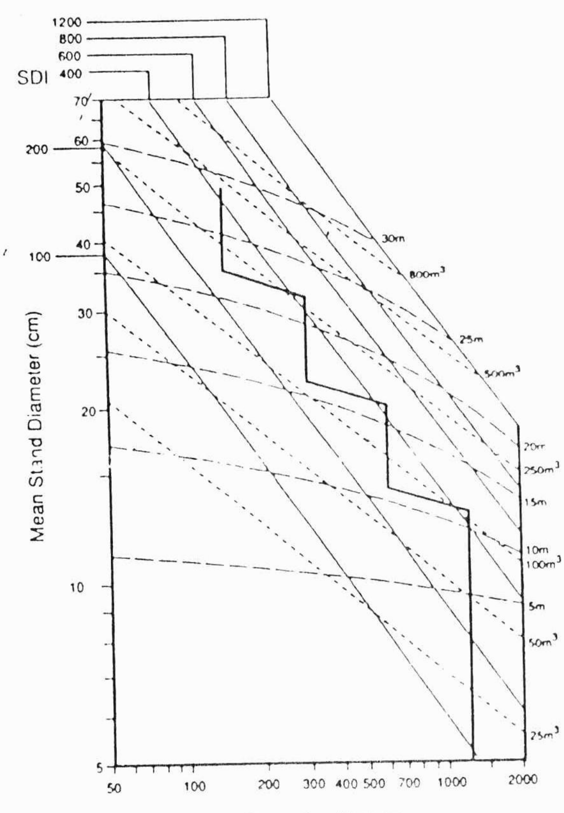
7.2.2. Log regime

This a more conventional density management regime intended to provide a combination of poles and large logs.



A density management regime for the production of poles.

Fig. 3



A density management regime for the production of logs and poles.

Fig. 4

Table 1
Examples of "key" SDI values for teak

Stand development events	Percent of maximum	SDI for teak
Maximum	100	1200
Lower limit for self-thinning	60	720
Lower limit for "full site occupancy"	35	420
Onset of competition	25	300

Table 2
Comparison of two density management regimes (EOR is end-of-rotation; CT is commercial thinning)

	Age (year)	Height (m)	TPH		D_q (cm)		Removed TPH	Volume (m^3 ha
			Before	After	Before	After		
Pole production regime								
CT	29	15.5	1600	700	15	18.2	900	140
EOR	45	21	700	–	25	–	700	340
Total yield 480 m^3 ha^{-1}								
MAI 10.7 m^3 ha^{-1} $year^{-1}$								
Log production regime								
CT	17	11	1200	600	13	14	600	30
CT	30	16	600	300	20	22	300	50
CT	49	22	300	240	31	35	60	85
EOR	74	29	140	–	50	–	140	450
Total yield 615 m^3 ha^{-1}								
MAI 8.3 m^3 ha^{-1} $year^{-1}$								

The minimum commercially utilizable pole was of 10 cm and target end-of-rotation Dq was 50 cm. The upper and lower limits of SDI was 420 (35 % of max SDI) and 240 (20 % of max SDI) respectively. Fig. 4. Gives the density management regime and the values are summarised in table 2.

8. Limitations of DMD

As any other tool, density management diagrams also have disadvantages. One limitation is their lack of memory concerning the effects of competetion prior to thinning. Another potential source of error is from the assumption that there is a single maximum size density relationship for a species. Most of the diagrams are based on a single species evenaged plantations.

9. Conclusion

The control of density levels in a stand has tremendous impact on that stands structure, productivity and ability to produce a variety of resources. Density management diagrams are the most comprehensive of all models developed for stand management. The principal advantage of density management diagrams is in predicating and displaying the consequences of stand density manipulations. Density management diagrams incorporates most of the complex stand developemnt process and converts them into simple stand management prescriptions. They can be, in addition to density management, used to evaluate several other objectives including wild life habitat management. The density management diagrams are of tremendous importance in stand management, since they are biologically sound, eaily applied and flexible in facilitating a wide range of management objectives.

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