The thinning quotient - a relevant description of a thinning?

Gallringskvot - en tillförlitlig beskrivning av en gallring?

Lars Henriksson

Arbetsrapport 7 1996

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Examensarbete i skogsuppskattning och skogsindelning
Handledare: Göran Ståhl

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FÖRORD

Denna uppsats utgör en del av ett examensarbete som utförts i slutskedet av jägmästarutbildningen. Ett av syftena med examensarbetet är att på ett så vetenskapligt sätt som möjligt tillämpa de kunskaper som man fått tidigare under utbildningen. Mitt examensarbete, som totalt skall motsvara 20 veckors heltidsstudier, består av två separata delar. Förutom denna del, som innehåller en teoretisk analys och granskning av hur gallringsformen beskrivs med hjälp av gallringskvoter, ingår även en inventering och utvärdering av utförda gallringar vid Söderhamns skogsförvaltning, STORA Skog AB.

Handledare under hela examensarbetet har varit Skog Dr Göran Ståhl, institutionen för skoglig resurshushållning och geomatik vid Sveriges lantbruksuniversitet. Han har på ett utmärkt sätt genom sina tips och synpunkter hela tiden lett arbetet framåt. Jag har dessutom honom att tacka för den språkliga granskningen av den engelska texten.

Umeå, februari 1996

Lars Henriksson

ABSTRACT

Thinnings can be described in many different ways. Frequently, however, the “thinning quotient“ is used as a descriptor. This quotient is usually expressed as the ratio between a mean diameter of the trees extracted and the trees left, although many definitions exist. In this study, the appropriateness of different definitions is evaluated through thinning simulations, sampling simulations, and analyses of the impact of strip-roads. The conclusion is that the value of using thinning quotients as descriptors seems to be limited.

Key words: sampling simulation, strip-roads, thinning, thinning quotient.

REFERAT

Det finns en rad sätt att beskriva gallringsformen. Ofta används begreppet gallringskvot i dessa sammanhang utan att närmare ange vilken metod eller definition som använts för att beräkna den. Detta kan lätt leda till att missuppfattningar uppstår. Denna studie belyser olika definitioners känslighet för bland annat beståndsstruktur, gallringsform och stickvägsavstånd. Studien innehåller dessutom en jämförelse mellan olika metoder att mäta och uppskatta gallringskvoten i ett bestånd. Slutsatsen är att gallringskvotens användbarhet och tillförlitlighet i många sammanhang är starkt begränsad.

Sökord: gallring, gallringskvot, inventeringssimulering, stickvägar

CONTENTS

INTRODUCTION

Reliable and realistic descriptions of thinnings are important in forestry for many reasons. Future growth will depend on which trees are removed as will also the value of the remaining stand. In multiple-use forestry, the size and species distribution of trees influence e.g. biodiversity and landscape amenity values.

For planning purposes and knowledge exchange, it would be valuable to have a clear terminology regarding the description of thinnings. Such a terminology should be based on solid grounds.

In the literature, thinnings are sometimes described by relating the diameter distribution of trees removed to the diameter distribution before thinning (e.g. Murray & von Gadow 1991). At other occasions, mainly in practical forestry, thinning are described rather indistinct in terms of "high thinning" and "thinning from below" (e.g. Füldner & von Gadow 1994). A frequently used descriptor is the thinning quotient, which is usually expressed as a ratio of mean diameters of extracted trees and trees left. However, there exist many different definitions of how the thinning quotient should be calculated (Frohm 1994). The definitions can be divided into three groups. The first involves a relation between a mean diameter of the extraction and a mean diameter of the trees left. Possible mean diameters are the arithmetic (Nordberg & Olsson 1988), the basal area weighted, and the diameter corresponding to the mean tree basal area (Carbonnier 1954, Vuokila 1977, Eriksson 1986). The second group relates the mean diameter of the extraction to the mean diameter in the stand before thinning (Braastad 1975, Agestam 1979, Eriksson & Eriksson 1993). The third alternative is a quotient between the basal area and number of extracted trees. The definitions are given in more detail in Table 1.

A desirable thinning descriptor should preferably have the following properties:

i) It should be logical and easy to understand.
ii) It should describe a specific kind of thinning in the same way regardless of the stand type.
iii) It should be possible to determine objectively, easy to calculate, and robust with regard to errors in the variables used to derive it.

The information needed to describe a thinning can be collected in many ways. Before the extraction, the trees to be removed and the trees to be left can be calipered. After a thinning, the diameters of removed trees can be determined by regression estimating the breast-height diameters using the diameters of the stumps. Also, it should in some cases be possible to obtain the diameters of cut trees from the computer that guides the bucking in harvesters. Contrary to using individual tree diameters, stand information about basal area and trees per hectare before and after a thinning can be used. Then, no time- and cost-consuming calipering is necessary.

The strip-roads often introduce problems in estimating thinning descriptors. With a distance between strip-roads below 20 m, which is rather common in e.g. Sweden today, the non-selective imperative extraction constitutes a large part of the total thinning removal (Fig. 1).

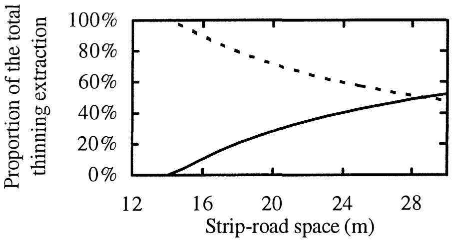


Fig. 1. The total thinning extraction (basal area) in and between the strip-roads in an idealised first-thinning. Strip-road width 4.3 m 30 % total extraction of the basal area.
- - - - Extraction in the strip-roads
—— Extraction between the strip-roads

The aim of this paper is, with reference to the properties of a good descriptor of a thinning outlined above, to evaluate the appropriateness of the different thinning quotients given in Table 1. The evaluations are made in three steps. Firstly, the different definitions are compared in different stand types. Secondly, the impact of errors in variables used for calculating thinning quotients is studied. Thirdly, studies are performed to evaluate the influence of different strip-road distances.

MATERIALS AND METHODS

The definitions of thinning quotients are given in Table 1. If the diameters of all or a sample of trees before and after a thinning are known, it is possible to use all the definitions. In case only standwise data (basal area and number of trees per hectare) are available, quotients 3, 6 and 7 can be used.

Table 1. Definitions of thinning quotients.
AMD = Arithmetic mean diameter, BWD = Basal area weighted mean diameter, DCB = Diameter corresponding to the mean tree basal area, d = diameter, n = number of trees, b = total basal area
index bt = the stand before thinning, index ex = the extraction, index at = the stand after thinning

	Definition	Mathematical definition
Group 1:		
Quotient 1	AMD of the extraction / AMD in the stand after thinning	$(\Sigma d_{ex}/n_{ex})/(\Sigma d_{at}/n_{at})$
Quotient 2	BWD of the extraction / BWD in the stand after thinning	$(\Sigma d_{ex}^3/\Sigma d_{ex}^2)/(\Sigma d_{at}^3/\Sigma d_{at}^2)$
Quotient 3	DCB of the extraction / DCB in the stand after thinning	$\sqrt{\frac{\Sigma d_{ex}^2}{n_{ex}}} \Big/ \sqrt{\frac{\Sigma d_{at}^2}{n_{at}}} = \sqrt{\frac{n_{at} * (b_{bt} - b_{at})}{b_{at} * (n_{bt} - n_{at})}}$
Group 2:		
Quotient 4	AMD of the extraction / AMD in the stand before thinning	$(\Sigma d_{ex}/n_{ex})/(\Sigma d_{bt}/n_{bt})$
Quotient 5	BWD of the extraction / BWD in the stand before thinning	$(\Sigma d_{ex}^3/\Sigma d_{ex}^2)/(\Sigma d_{bt}^3/\Sigma d_{bt}^2)$
Quotient 6	DCB of the extraction / DCB in the before thinning	$\sqrt{\frac{\Sigma d_{ex}^2}{n_{ex}}} \Big/ \sqrt{\frac{\Sigma d_{bt}^2}{n_{bt}}} = \sqrt{\frac{n_{bt} * (b_{bt} - b_{at})}{b_{bt} * (n_{bt} - n_{at})}}$
Group 3:		
Quotient 7	Relation between extractions expressed in basal area and number of trees	$\frac{b_{bt} - b_{at}}{b_{bt}} \Big/ \frac{n_{bt} - n_{at}}{n_{bt}} = \frac{n_{bt} * (b_{bt} - b_{at})}{b_{bt} * (n_{bt} - n_{at})}$

Comparisons in different stands

In order to compare the different definitions' sensitivity to stand structure, thinnings were simulated in four stands with different diameter distributions (Fig. 2). The stands were artificially created in order to obtain extreme cases. Studies were, however, also carried out in real stands in order to verify the results.

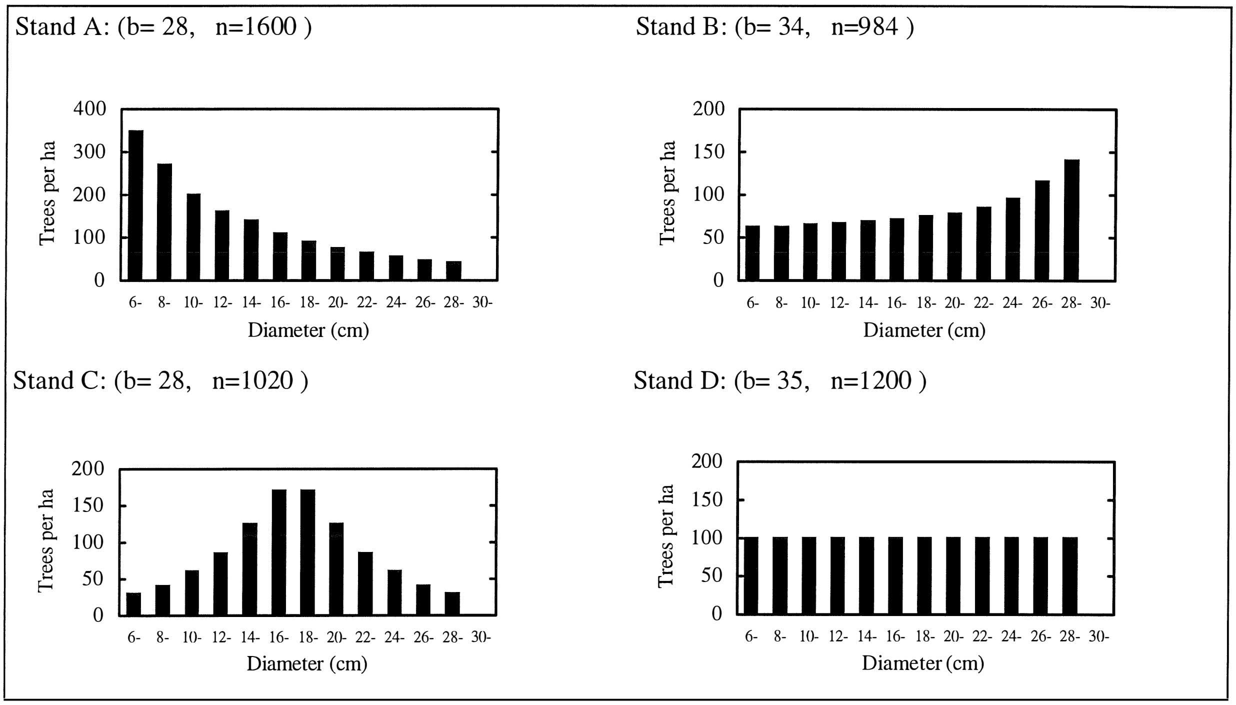


Fig. 2. The diameter distributions, the basal areas, m^2 ha^{-1} (b), and the number of stems, ha^{-1} (n), in the stands A-D.

Common for all simulations was a constant extraction of 30 % of the basal area. Strip-roads were in this case supposed to be present in the stands prior to the thinnings. Four extreme kinds of thinnings were tested. They can be characterised as follows:

a) Thinning from below: A step by step removal of the smallest trees until 30 % of the basal area was extracted.
b) Thinning from above: As above, but starting with the largest trees.
c) Thinning from the middle: Starting from the arithmetic mean diameter of the stand, larger and smaller trees were extracted until 15 % of the basal area was reached in both directions.
d) Thinning from both sides: Removal of both the smallest and the largest trees. A 15 % basal area extraction both from above and below.

Tree locations were not considered in the thinning simulations.

Since the thinning quotient is a descriptor which only describes the orientation, it should preferably be independent of the extraction rate. To study this, different extraction rates at thinning from below and thinning from above were simulated. In this study, only quotients 3 and 6 were compared.

Impact of errors

A reliable thinning descriptor should preferably be rather insensitive to errors in the input information used to calculate it. If information from a total tally of trees is available, this is not a problem. Due to budget restrictions, however, some kind of sampling procedure is usually necessary. The quality of the information acquired is then influenced by the sampling design and the structure of the forest. Two principally different inventory designs were tested in this study. Firstly, a random systematic sample plot inventory was tested. Secondly, a subjective inventory method was tested. The two cases are described below.

Using sample plot inventory, the sensitivity of different thinning quotients to sampling errors was studied using Monte Carlo simulations. Forests with known tree locations were made available digitally and a specific sampling design was carried out repeatedly in a computer. Thereby it was possible to estimate the accuracy in terms of the mean square error (MSE), since $\mathrm{MSE}=E(Q-Q_{true})^2$ where Q is the estimated quotient and Q_{true} is the true one.

Two different four-hectare forests were simulated according to a Poisson process for both tree location and size (Table 2). The thinnings in the forests were assumed to be made from below (case a). On each sample plot the diameters of trees to be left and trees to be cut were acquired. In this study, quotients 1 and 4 were used.

Table 2. True values about the simulated stands. AMD is the arithmetic mean diameter, and n is the number of trees per hectar

Variables	Stand 1 (homogenous)	Stand 2 (heterogeneous)
AMD of the extraction (cm)	14.4	15.6
AMD in the stand after thinning (cm)	16.3	16.3
n removed	600	600
n after thinning	1 000	1 000
Quotient 1	0.88	0.95
Quotient 4	0.92	0.97

In each of the forests, two random systematic designs with ten circular sample plots were tested. The difference between designs was due to different plot radii (10 metres and 6 metres).

Using subjective inventory methods, sampling simulation can no longer be used to evaluate the accuracy of estimated thinning quotients. This is due to the difficulty of simulating subjective judgements. From subjective inventories, standwise mean values are usually available. To study the reliability of using this kind of data in estimating thinning quotients, an analytic method based on Taylor approximation (e.g. Miller 1972) was used. If the variances of variables, as well as the covariances between them, are known, the following formula can be used to approximate the mean square error (MSE):

$$\mathrm{MSE} = E(f(\mathbf{x})-f(\mathbf{x}_0))^2 \approx \sum_{i=1}^{n}\left(\frac{\partial f(\mathbf{x}_0)}{\partial x_i}\right)^2 \mathrm{Var}(x_i) + 2\sum_{i=1}^{n}\sum_{k>i}^{n}\left(\frac{\partial f(\mathbf{x}_0)}{\partial x_i}\right)\left(\frac{\partial f(\mathbf{x}_0)}{\partial x_k}\right)\mathrm{Cov}(x_i, x_k)$$

where

f($\mathbf{x}$) is the formula for the thinning quotient

$\mathbf{x}$ is a vector of estimated stand variables (x_1 , x_2 ,...)

$\mathbf{x_0}$ is the true value of the vector

n is the number of stand variables used to calculate the thinning quotient

Quotients 3 and 7 were analysed in this way. Different values of $\mathbf{x_0}$ result in different MSEs. The $\mathbf{x_0}$ values used in the study are given in Table 3. They were chosen to represent an ordinary type of stand at the time of first thinning according to an inventory of thinnings made in the middle of Sweden (Söderhamn) in 1994 (Henriksson 1995).

Table 3. Stand characteristics used in the study

Variable	Before thinning	After thinning
Total basal area (m²/hectare)	28	19
Number of trees per hectare	1600	1000
Quotient 3		0.89
Quotient 7		0.86

The precision of the variables (Table 4) used, stems from a study of subjective inventory methods (Ståhl 1992) and from a study of thinnings (Henriksson 1995). The basal area was estimated by relascope while the number of trees was purely subjectively estimated by people practised in forest inventory. No studies are available about covariances between the variables of interest. In this study, the correlation between basal area before and after thinning and between the number of trees before and after thinning was set to 0.9. (Correlation is another way to express the covariance.) The high correlation is motivated by the assumption that there is a large probability that a too high/low estimation before thinning is followed by a too high/low estimation after thinning, since the value before thinning and an approximate estimate of the removal are known to the surveyor. All other correlations were set to zero. The estimated values were assumed to be unbiased.

Table 4. Standard deviations (Sd) of variables used in the study

Variable	Sd (%)
Ståhl, 1992:	
Basal area (b_1 and b_3)	11
Number of trees per hectare (n_1 and n_3)	31
Henriksson, 1995:	
Basal area (b_1 and b_3)	14
Number of trees per hectare (n_1 and n_3)	19

Strip-road effects on thinning quotients

The first two studies were performed ignoring the effect of strip-roads on the thinning quotients. Strip-roads were assumed to be present in the stands. In first thinnings, however, the estimated values of thinning quotients will be largely influenced by the width and spacing of strip-roads. This is due to the imperative removal of trees in these roads.

Assuming a totally systematic strip-road system, it is possible to calculate the proportion of the total basal area thinned in and between the strip-roads (Fig. 1). Two different analyses were made in order to study the effect of strip-roads. In the first study, thinning quotients 1 to 3 (Table 1) were used in stands A and B (Fig. 2) to illustrate the differences in thinning quotients in and between strip-roads for different kinds of thinnings. The mean diameter of extracted trees was calculated separately for the roads and the area between roads. This mean diameter was then related to the mean diameter of the stand after thinning. The strip-road width was 4.3 metres and the distance between the roads was 20 metres. In the second study, the effect of different strip-road distances was studied, given a 30% total extraction of basal area. Here, quotient 2 was used for two different thinning quotients between the strip-roads (0.7 and 1.3).

All calculations were based on the assumption that an equal proportion of trees from all diameter classes were cut in the strip-roads. According to Fröding (1982), however, this may not be the case, since strip-roads are more or less winding.

RESULTS

Comparisons in different stands

For a majority of the cases, there were large differences between quotients calculated according to different definitions (Fig. 3). The following general observations can be made:

- The quotients using mean diameters before thinning in the denominator (quotients 4, 5 and 6) always give a value closer to 1.0 than the corresponding quotients using the mean diameter of the stand after thinning (quotients 1, 2 and 3). This, of course, is expected.
- A specific quotient mostly results in values of similar magnitude in the different stands, given a certain thinning. A few exceptions exist (e. g. quotient 7 in some cases).
- A certain quotient may assume similar values under very different kinds of thinnings in a stand.
- In all cases, except thinning from the middle, quotient 7 is more extreme than the other quotients.
- At a comparison between the use of different mean diameters, the quotients with basal area weighted mean diameter are higher than, in turn, quotients using the diameter corresponding to the mean tree basal area and the arithmetic mean diameter. This is the case in all situations except thinning from the middle. In general, the difference is largest between quotient 1 and quotient 2.
- At thinning from the middle there was another order between quotients with different mean diameters. The reason is that the extraction has a mean diameter higher than the arithmetic mean diameter but lower than the basal area weighted mean diameter. As a consequence, the quotients 1 and 4 were higher than 1.0 in stand A, but the quotients 2 and 5 were lower than 1.0.

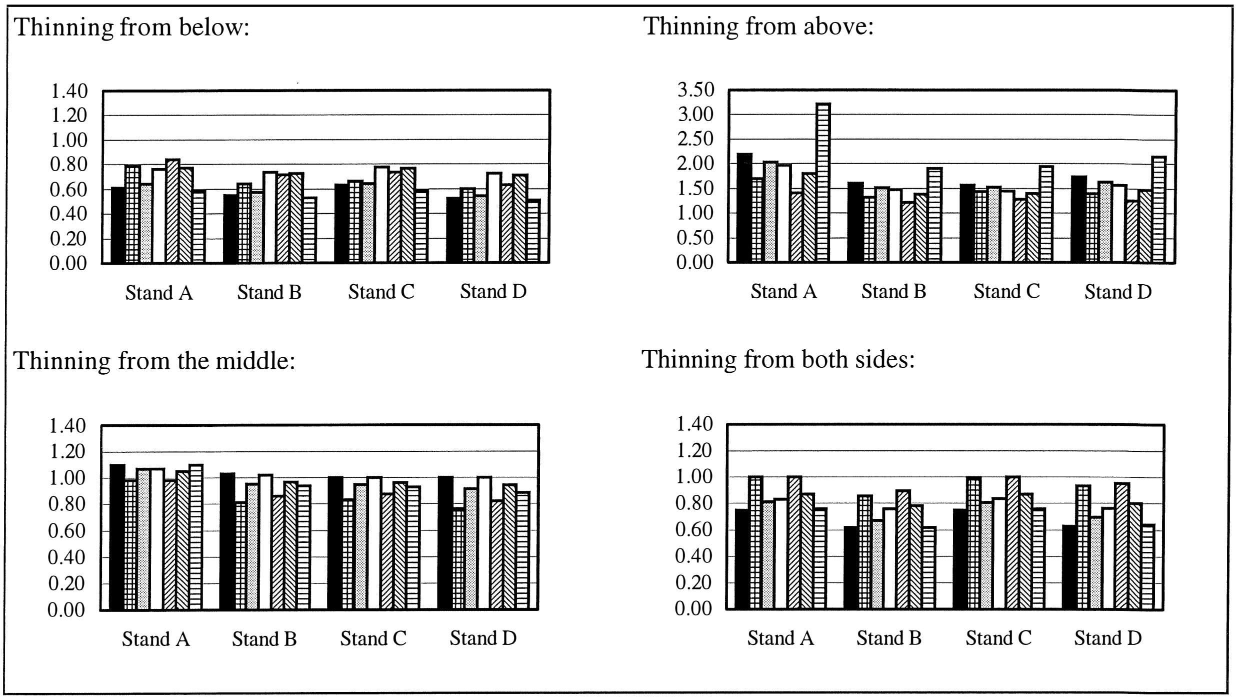


Fig. 3. Thinning quotients in the different stands. Quotients in each stand are given in order 1 to 7. Note the different scales.

For quotient 6, there was an obvious correlation between the quotient's size and the extraction rate (Fig. 4). For both types of thinnings studied the quotient tended to 1.0 when the extraction rate increased. The size of quotient 3 was more stable, at least within reasonable extraction rate ranges.

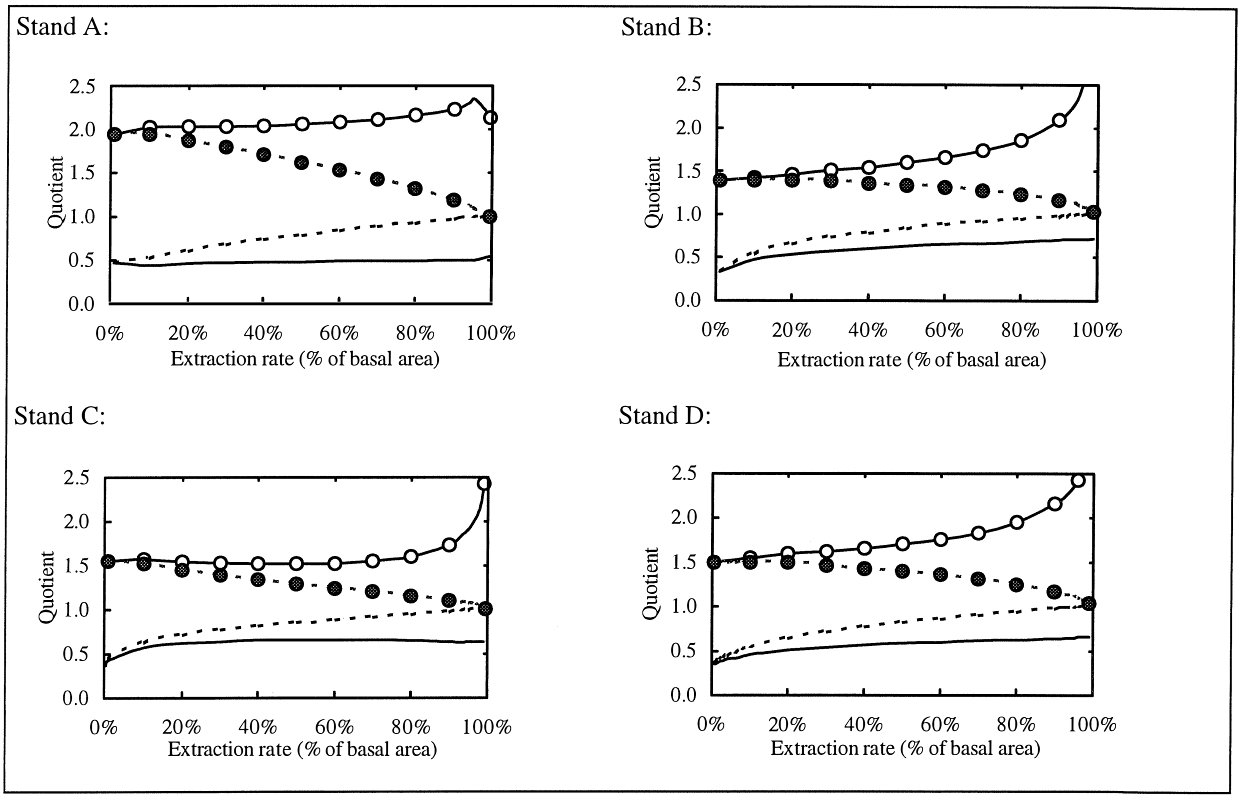


Fig. 4. The influence of the extraction rate on the thinning quotient. —O— Quotient 3, thinning from above, - -●- - Quotient 6, thinning from above, —— Quotient 3, thinning from below, - - - - Quotient 6, thinning from below.

Impact of errors

The results from the sampling simulations using a systematic sample plot design are given in Table 5. The RMSE (Root mean square error) of the thinning quotients are small both in the homogenous and the heterogeneous stand. As expected, the accuracy increases with plot size.

Table 5. RMSE of quotients 1 and 4 in a systematic sample-plot inventory

	Homogenous stand		Heterogenous stand	
Radius of the sample plots	10 m	6 m	10 m	6 m
Quotient 1	0.020	0.048	0.038	0.069
Quotient 4	0.014	0.032	0.025	0.045

The situation was different when the thinning quotients were calculated using subjectively estimated standwise mean data (Table 6). In this case, the RMSE was larger than 0.2 in some cases which indicates very inaccurate estimations of the thinning quotient.

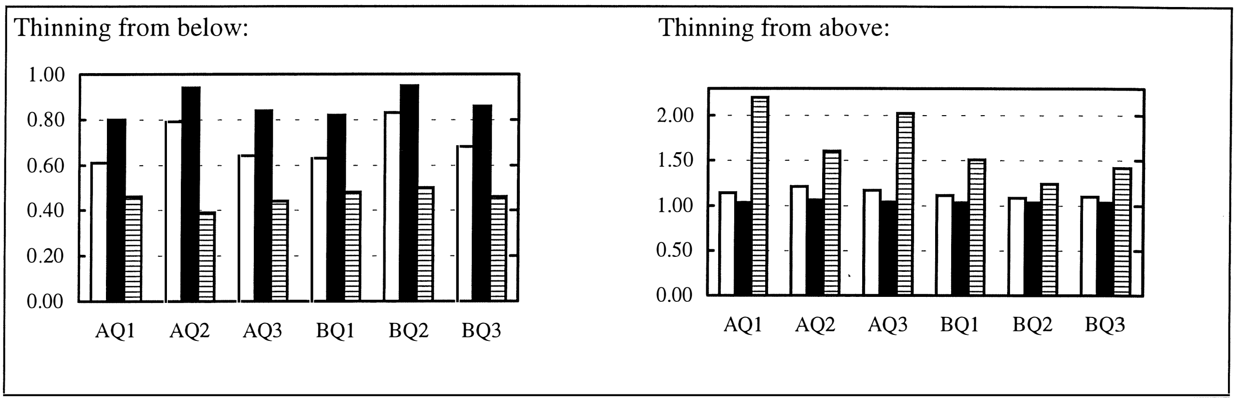
Table 6. RMSE of quotients 3 (Q3) and 7 (Q7) in subjective inventory

Reference concerning the reliability of input variables	Q3	Q 7
Ståhl, 1992	0.179	0.217
Henriksson, 1995	0.134	0.167

Strip-road effects

At extreme selective thinning between strip-roads (cases a and b) and a uniform extraction in the strip-roads there is a large difference between the thinning quotient for the entire stand and the quotient calculated for the area between the roads (Fig. 5). Since the mean diameter in a stand is higher after than before a thinning from below, the thinning quotients for road-trees were below 1.0 in this case. Correspondingly, there were large differences when thinning from above was applied.

At decreasing strip-road spacing the thinning quotient of the whole stand became more and more similar to the quotient for the road trees (Fig. 6). The reason is, of course, the increasing part of the total extraction in the strip-roads (Fig. 1).


Thinning from below:

Thinning from above:

Fig. 5. Quotients (Q) 1,2 and 3 in stand A and B calculated for the total stand (□), for the strip-road removal (■) and for the removal between the strip-roads (≡) at thinning from below and thinning from above. Observe the different scales.

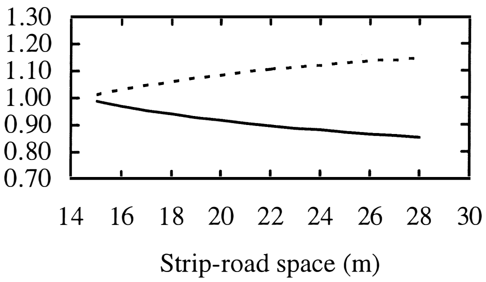


Fig. 6. Thinning quotients at the stand level at different strip-road spaces and different quotients between the strip-roads. The extraction was 30 % of the basal area.
Quotients between the strip-roads: —— = 0.70 , - - - - - = 1.30

DISCUSSION

It must be considered appropriate to use tree diameters (and of course species) in describing the orientation of the extraction in thinnings. Another possibility would be to use tree heights. Heights, however, are much more difficult to measure and since diameters and heights usually correlate well the need to measure heights seems to be limited. But how useful descriptors of thinnings are the different thinning quotients? This will now be discussed from the viewpoint of the preferable properties of a thinning descriptor given in the introduction.

Firstly, a thinning descriptor should be logical and easy to understand. When thinnings are entirely from below (case a) or from above (case b) thinning quotients, independent of definition, are rather logical and intuitively easy to understand. The quotients 1 to 3 result in the most distinct values (values well away from 1.0). These quotients use information about the stand after thinning as a reference in the denominator. However, since stand characteristics after thinning are influenced by the thinning, the reference in this case will depend on how the thinning is carried out. From a logical point of view, therefore, quotients 4 to 6, which use stand information before thinning as a reference, seem to be preferable.

A disadvantage with all thinning quotients is that they are influenced by the extraction rate. This is most obvious for the quotients 4 to 6. For these, the mean diameter of the extraction will be more and more similar to the mean diameter of the stand before thinning when the extraction rate increases. The result is a quotient that approaches 1.0. These quotients should therefore be supplemented with the extraction rate for the description to be more complete. Another possibility would be to develop a descriptor that considers both the traditional diameter ratio and also the extraction rate in one single expression., e.g.: $Q - (0.5 - ER) * (Q -1)$, where Q is some thinning quotient and ER is the extraction rate.

However, for quotients 1 to 3 the correlation with the extraction rate is not so obvious. At e.g. thinning from above, the mean diameter of the extraction will decrease with increasing extraction rate. But at the same time, the mean diameter of the stand after thinning will decrease. In some stand types, the ratio will be almost constant. In other cases the quotient will increase. In general, however, the influence of extraction rate is moderate for these thinning quotients, at least in the interval of normal extraction rates.

When thinnings are not from below or from above, the intuitive logic of thinning quotients vanishes. For example, the two very different operations "thinning from both sides" (case d) and "thinning from the middle" (case c) resulted in thinning quotients of equal magnitude. In practical thinnings (e.g. Henriksson 1995), trees are removed from all diameter classes not only due to strip-roads, but also due to calamities and tree quality considerations. As a result, the thinning quotients will be less distinct.

Perhaps of minor importance is the question of which kind of mean diameter to use. The quotients with basal area weighted mean diameters are less influenced by small trees than the two other kinds of mean diameters, especially at thinning from below. An advantage of the arithmetic mean diameter is that it is easy to calculate and understand. However, the often large differences between thinning quotients under different definitions make it necessary to clearly state which of them is used.

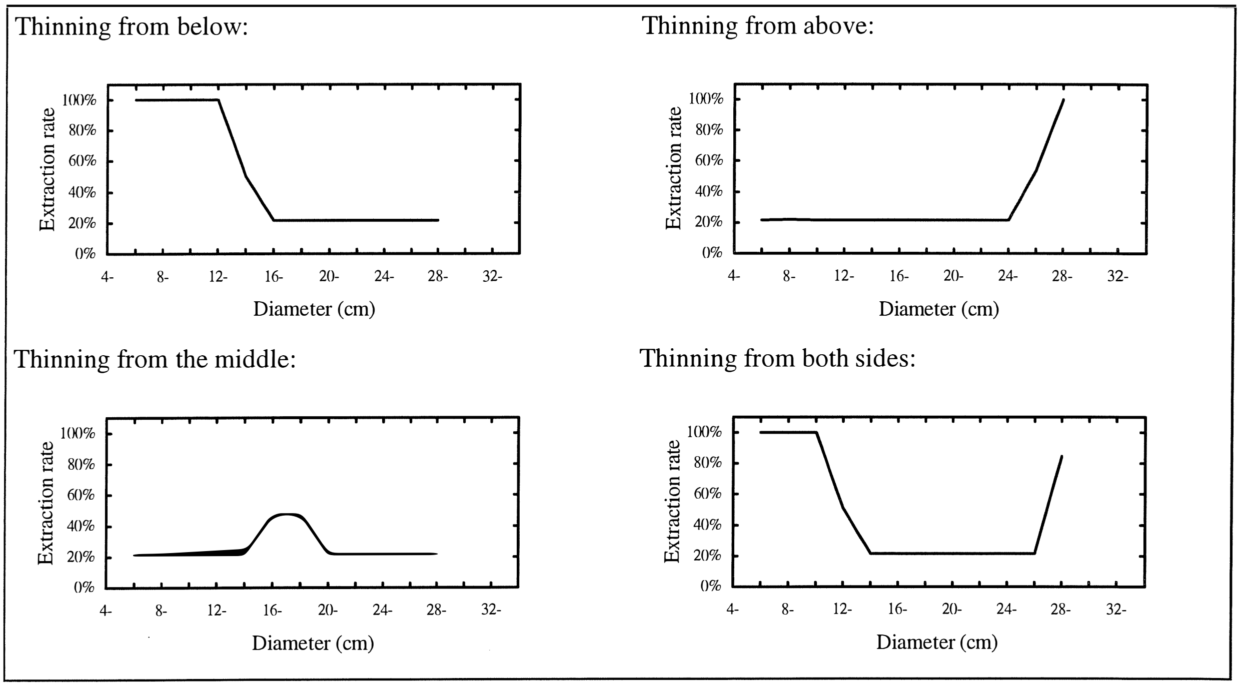
Further, it is questionable if thinning quotients should be calculated for the entire stand in first thinnings. In such cases, the width and spacing of strip-roads have tremendous impact on the thinning quotient. For this reason, it would be better the consider only the trees removed between the strip-roads in the calculations. Such a quotient could be supplemented by the area proportion of strip-roads within the stand.

To return to the properties of a thinning description given in the introduction, a second preferred property is that a descriptor should describe a specific kind of thinning in the same way regardless of stand type. The results in this study indicate that the different thinning quotients meet this requirement.

Thirdly, descriptors should be possible to determine objectively and they should not be too sensitive to errors in variables used to derive them. All the quotients studied are perfectly possible to determine objectively. Concerning their sensitivity to errors, the reliability of thinning quotients seems to depend on a rather intensive sample plot inventory. Using such inventory methods, thinning quotients can be determined very accurately. However, if sample plot data are available a much better description of a thinning can be extracted from the data. As presented by Murray & von Gadow (1991), a diagram with extraction rates in each diameter class provides a very good picture of a thinning operation. Such a diagram can easily be constructed if sample plot data with calipered trees are available. Examples of such diagrams are given in Fig. 7.

Still, thinning quotients could be useful in cases when available data do not allow diagrams of the kind described to be constructed. This is the situation in cases when data about the stand are only present in terms of stand mean values, e.g. from subjective inventories. To judge from the results concerning the accuracy of estimated quotients in such cases, however, the usefulness of thinning quotients must be questioned. The RMSEs ranged from 0.13 to 0.22. This indicates severe uncertainty.

Our final conclusion, therefore, is that the value of using thinning quotients as descriptors of thinnings seems to be limited.



Thinning from below:

Thinning from above:

Thinning from the middle:

Thinning from both sides:

Fig. 7. Different cases of thinnings in stand C characterised with extraction rates in each diameter class.

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