MODELLING PROCESSES OF PLANTING STOCK PRODUCTION AND ESTABLISHMENT: FRAMEWORK OF THE MODEL AND ITS USE IN PRACTICE

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ABSTRACT

A model framework is presented in attempting to describe the production of forest tree seedlings as a continuous uninterrupted process according to general principles of systems theory. The growth and development of a seedling lot is considered to be the product of two hierarchical processes: the development and growth of the individual seedlings and the management techniques used in their production. The functional structure as the processes develop is described. For the detailed analysis, the growing process is divided into different phases each relating to the factors affecting the development of the seedling lot. The height distribution development of planted seedlings is given as an example. The use of culling and grading in the control of the growing process is examined.

INTRODUCTION

The aim of forest establishment is to obtain fully-stocked, healthy, vigorous seedlings in a reasonable time at moderate cost. The processes involved in achieving this aim include seed production, seedling production in the nursery, seedling transport, preparative work at the regeneration site and tending of the seedling stands.

In the nursery and at the planting site, there is a complicated biological process at one level, technical problems at another and economic necessities at the third. Research effort is usually divided according to these levels, but is often also divided on the basis of the chronological stages of growth or applied to specific problems, such as improving the seedling quality. In practice, however, it is important to treat the production process from the seedling phase in the nursery to thinning in the forest as a whole. No single phase in the production of seedlings can be examined without taking into account its effects on the treatments preceding and following it and on the final result.

Forming a comprehensive picture of the growing process of a seedling lot in terms of research and nursery practice is extremely difficult. Systems theory based on cybernetics has provided an opportunity to study such complex processes in various disciplines

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including ecology, industrial processing, agriculture and pasture research and this approach should also be useful in solving forest regeneration problems.

A model framework for seedling production is presented as a complete, uninterrupted process outlining a set of the basic components of the growing process according to the general principles of systems theory (Kremyanskiy, 1958; Goodall, 1972; Goodall, 1976; Hall and Day, 1977) in a way that reflects their logical relationship with concepts used in physics and engineering. This will enable us to use the effective tools provided by systems analysis for studies and decisions relating to the seedling production.

SEEDLING PRODUCTION AS A BIOTECHNICAL PROCESS

Subsidiary factors and phases of the process

Growing forest tree seedlings in the nursery, lifting transporting, planting and tending of the stand after planting can be treated as a biotechnical process, the progress of which can be measured and directed. We can either measure and direct the process itself, the growth and development of the seedling lot, or assess the product of the process, the seedlings, which constitute an ever-decreasing number of individuals as they mature from seeds to seedlings.

The process is described in Fig. 1. A depicts the initial state, the seed lot, from which the seedlings are grown , B the transformation from the initial state to the end product, i.e., the growing process, and C the end product. In practical calculations A and C are usually vectors which describe some characteristics of the seedling lot and B is a matrix which describes the process.

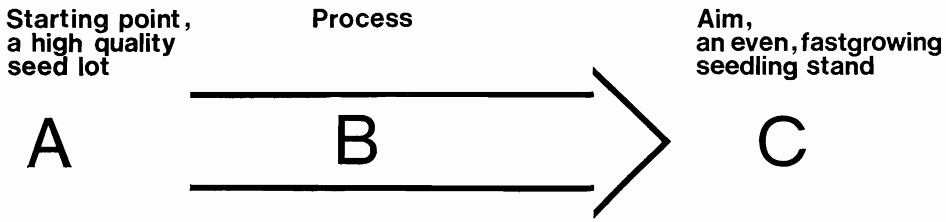

FIG. 1—Matrix transformation: the development process from seed lot to seedling stand.

During the growing process many factors affect seedling development and for a detailed analysis, it is helpful to divide the growing process into different phases on the basis of changes in the factors affecting the seedlings. The factors advancing or hindering the development are quite different in the nursery from these after planting out. In the main phases it is possible to distinguish subphases, which can be combined to form an ontogenic development stage, but this is not usually done. The number of phases distinguished depends on how significant they are from the point of view of the whole growing process. The relative importance of the technical and economic limitations to system control increases as the process progresses (Fig. 2) and the biological and technical information obtained from the process, on the basis of which the decisions are made varies from one growing phase to another. An attempt is made during the seedling nursery phase to control those factors affecting growth and to control any possible damage to the seedlings. During the time when the seedlings are

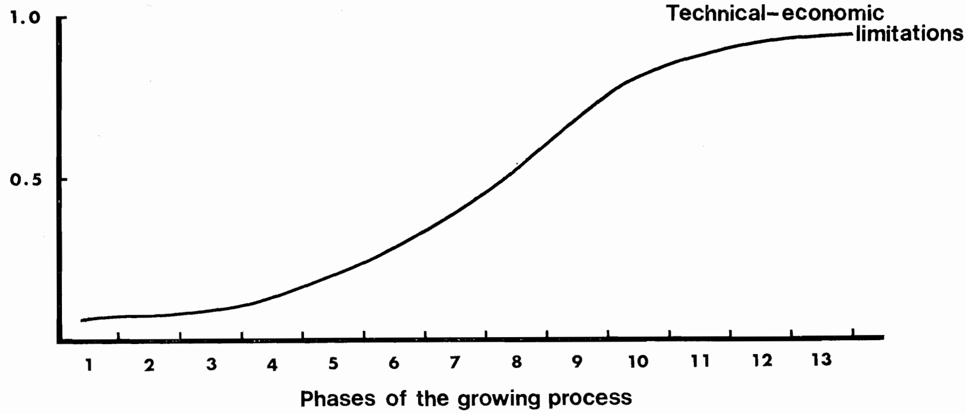

FIG. 2—The relative importance of technical-economic limitations on the growing of seedlings. Phases of the growing process are as follows:

000 Seed formation
00 Collection of seed
0 Storage of seed
1 Sowing phase
2 Germination phase
3 Germling phase
4 Seedling phase
5 Transplanting phase
6 Transplant phase
7 Transfer (lifting, packing, transport) phase
8 Planting phase
9 Planting shock phase
10 Weed phase
11 Snow limit phase
12 Establishment phase
13 Competition phase (differentiation into crown classes)

transferred from the nursery to the planting site attempts are made to prevent any weakening of the seedlings, to minimise stress and, only occasionally, to repair any earlier damage or speed up the rate of development. After planting out an immediate attempt is made to control the process by culling and grading the seedlings, selecting and preparing the planting site and maintaining a high planting standard. Measures carried out during later phases, which may sometimes include active damage control measures or even fertilisation are primarily aimed at reducing competition (Fig. 3).

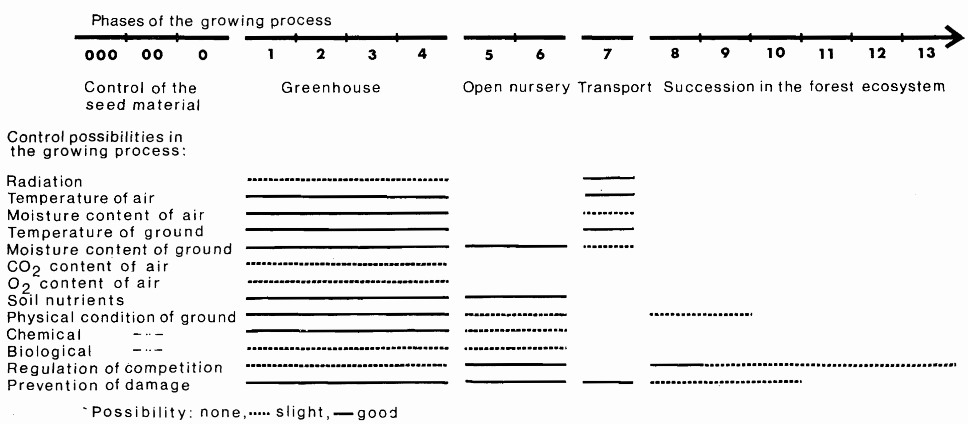

FIG. 3—Example of the control points for the different phases of the growing process.

Increased physiological research, the development of technical tools, machinery and automation should enable more strict control in the nursery phases of the process.

Functional structure and progress of the process

The growth and development of a seedling lot as a biotechnical process can be considered to be the product of two hierarchical processes: development of the seedling and its management. Functionally, the development process is transformed into a growing process by means of feedback regulation (Fig. 4). Both processes include on the one hand continuous development, and on the other discrete, irreversible phases.

The control points in the process are directed by those external factors, part of the input u, which can be affected by feedback regulation. Examples of the control points are choice and preparation of substrate, irrigation, fertilisation, and the temperature, relative humidity and carbon dioxide concentration of the air in the greenhouse. Disturbing points are those external factors, part of the input u_o, which cannot be

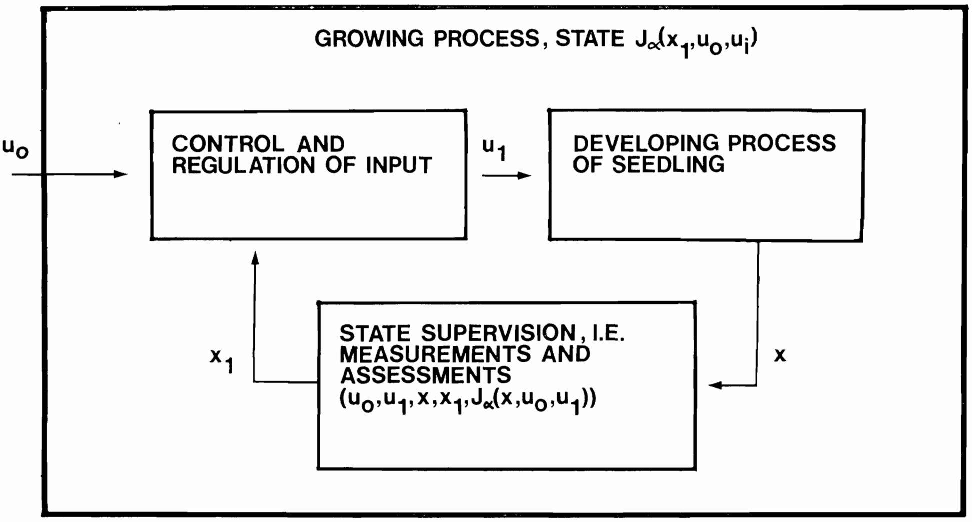

FIG. 4—Schematic diagram of the growing process, in which:

x	state of the development process of the seedling, e.g., biomass, nutrient concentration, water potential, photosynthesis, transpiration (or change in the rate of these), etc.
x_1	measurements carried out (+ estimates and observations)
u_0	input of the growing process: unregulated temperature, illumination, damaging agents, etc.
u_1	input of the development process of the seedling: environmental factors having an immediate effect on development by which means of feedback regulation (control based on state supervision and by control measures) is transformed from u_0.
$J_\alpha(x_1, u_0, u_1)$	the state of the growing process of the seedling, e.g., morphology (such as the root/shoot ratio), growth rates of the different parts of the seedling (such as the regeneration capacity of the roots), absorption/transpiration ratio, different ratios of x, u_0 and u_1, etc.

completely regulated. Control parameters are those state variables of the plant development process, the immediate input u_1, which affect the seedling response. Control measures are not, as such, included in the variables x, x_1, u_o, u_1, but are instead, linked through the "co-ordinator", a program of functions of the changes in the variables with time and affect the values used in the input, u_1. The values used in the co-ordinator change during a single development phase and are based on the information available from measurements (x_1). Between phases the structure of the model remains much the same as that shown in Fig. 4, and the general concept is valid for the whole growing process. However, individual parts may change significantly, for example between the transplanting and transfer phase.

If the development of the seedling in the model corresponds with the ontogenic development of the species under natural growing conditions then its progression is said to be normal; it is hypernormal when it takes place at a faster rate than the naturally growing seedling and under stress when it is slower. If the state of the seedling development in the model continues to be normal, then it follows the ontogenic development of the naturally growing seedlings. If the state of development differs from normal it is said to be "adapted to a certain limit" resulting in either a hypernormally or stressed seedling, the degree of which depends on the severity of the hypernormality or stress, and its duration. During the nursery phase it is usual to encourage hypernormal development and the development of stress is sometimes a goal if it is more beneficial for later phases of seedling production, e.g., if it is beneficial from the point of view of the seedling becoming adapted to conditions at a particular site.

Culling and grading as a part of the process

Data from assessments carried out before the transplanting and planting phases are important and can be used in the rejection or acceptance of seedlings, in selecting seedling material for transplanting at special planting sites and in controlling the products of the nursery phases. Much discussion has been concerned with the extent to which these measurements can be based on morphological characteristics, such as seedling height and diameter, and the extent to which they should be based on physiological classification (Wakely, 1948; Schmidt-Vogt, 1974).

Information about the seedling's development during the germination and growth phases in the nursery (x) is more important for control measures than is information about the state of the whole production process (J_α (x_1, u_0, u_1)) because it can be used to immediately affect the seedling development process. In practice, of course, most of the information collected during the nursery phases is about the degree and changes in morphological development since this is easy to obtain. When classifying seedlings for forest planting, assessments almost always describe their condition in terms of either morphological or physiological characteristics.

Physiological measurements primarily describe seedling responses such as drought resistance and not the condition of development, and this information is used in the control of the phases following lifting. A number of physiological characteristics, however, change rapidly and the period when physiological data remain valid is short. In fact, data from physiological studies are used to determine the time when the critical phases of the process, i.e., the transfer phase, the planting phase and the planting shock phase, occur and their significance is accentuated. These phases can be simulated beforehand and the response of the seedlings examined (Hallman *et al.,* 1978). The morphological measurements and classification do not necessarily lead to a conclusion about the state of development of the production process. Morphological characteristics can be measured even if seedlings are dead. When they are used it is always necessary to somehow ensure that the seedlings are in "good physiological condition".

A special problem in using a morphological classification is that a seedling lot grown under conditions as uniform as possible contains variation caused by several other factors, i.e., genetic factors, technical seed properties such as variation in size and germination vigour and variation caused by the nonuniform control throughout the process. Usually a particular property and the variation in its characteristics result from interaction between these different factors, and they cannot be separated out into their specific components.

Genetically poor material should be culled and physiologically weak seedlings should usually also be removed, although, in principle, it is possible to continue growing physiologically weak seedlings at the nursery in order to allow them to recover for later use. The rejection of morphologically weak small-sized and spindly seedling material is based on the idea that their small size may be due to poor genetic quality or physiological weakness reflected in morphological characteristics. Material which is smaller than average for the seedling lot can also be rejected on the expectation that the size differences will not even themselves out but rather increase as the seedling stand grows, and that small seedlings do not produce trees with the highest wood production. It is true that by this procedure some genetically good material is lost.

In seedling production on an industrial management scale the use of separate culling and grading activities decreases and quality control is carried out more and more in all other phases of the production process under state supervision regulations.

As a result good quality even-sized seedling material is obtained and the need for culling is greatly reduced. Culling based on simple morphological characteristics can be successful as long as the classification is not based on individual seedlings but on the seedling lot as a whole (i.e., "distribution classification"). Seedling lots with height and diameter distributions greater than normal are an assurance that there are no large physiological or genetical variations present.

AN APPLICATION

The theoretical model presented is dynamic and quantitative and the state of the seedling production process at a given moment, the forces bringing about the change in state and the rate of change are described by submodels. Numerical integration methods can be used for parts of the model even though the procedure is too complicated to be carried out from beginning to end, from the seed lot to the seedling stand, since the growing process has many structural discontinuities. Of course, it is impractical to make a detailed analysis of the state by state development of individual seedlings. When growing forest tree seedlings we are usually interested in the growth and development of the whole seedling lot and the aggregate characteristics are adequate.

As an example let us examine the development of planted seedlings during the period extending from the first autumn after planting out until the autumn of the seventh year after planting. Under Finnish conditions such a period includes the weed phase, snow limit phase and part of the field establishment phase of seedling development. Data from an earlier study of a planting trial (Yli-Vakkuri *et al.*, 1968) examining the winter storage of Scots pine (*P. silvestris* L.) seedlings, were used in this example. The experiments were established in two consecutive springs at two closely located sites in northern Finland (65° and 25° 30′) which differed in fertility. Altogether 750 (2/1) Scots pine seedlings were planted at each site and subsequently given identical treatment to those growing in the nursery beds.

After the first summer those seedlings planted out on the fertile site which were in good condition were included in the examination. These seedlings (about 600) were then divided into height classes on the basis of measurements carried out in successive years. The growth distribution of each class in each year during the seven year period was examined by following the transfer of seedlings between height classes in successive years. Let x_i be the height class distribution of the ith year. If height growth depends only on the height of the seedlings in the previous year, the distribution for the ith year is obtained from the distribution of the previous year by multiplying x_{i-1} by the growth matrix *A*. The distribution of the (i-1)th year x_{i-1}, is in turn obtained from the previous distribution x_{i-2}, etc.

$$x_i = A\ x_{i-1} = A\ .\ A\ .\ x_{i-2} = \ .\ .\ .\ A^i x$$

The growth matrix *A* is thus determined and, under the local conditions can be used to estimate the optimum growth of the Scots pine seedlings.

This growth matrix was then used to calculate the predicted annual height distributions of the seedlings in the other experiments on a less fertile site. It was found that the difference between the height distributions during the seedling growth phase could largely be attributed to differences in site fertility, which also included the climatic variations during two successive years. Later on there was a negative skew, a "tail", in the actual distribution (Fig. 5a) which was apparently due to damage that occurred on the less fertile site. Growth matrix *A* was then used to calculate the height class distributions in different years for healthy seedlings in the experiment at the less fertile site. The calculation was affected by the fact that there were relatively few seedlings (296). It was found that initially the calculated height distributions did not compare well with the actual ones but, after a two-year lag the agreement improved considerably (Fig. 5b). This means that with a rather simple additional term the model developed with material on a good site can be extended to cover the growth processes of material on a poor site.

The model is being developed to take into consideration the effects of other factors on growth such as fertility, damage, fertilisation and other controlling variables.

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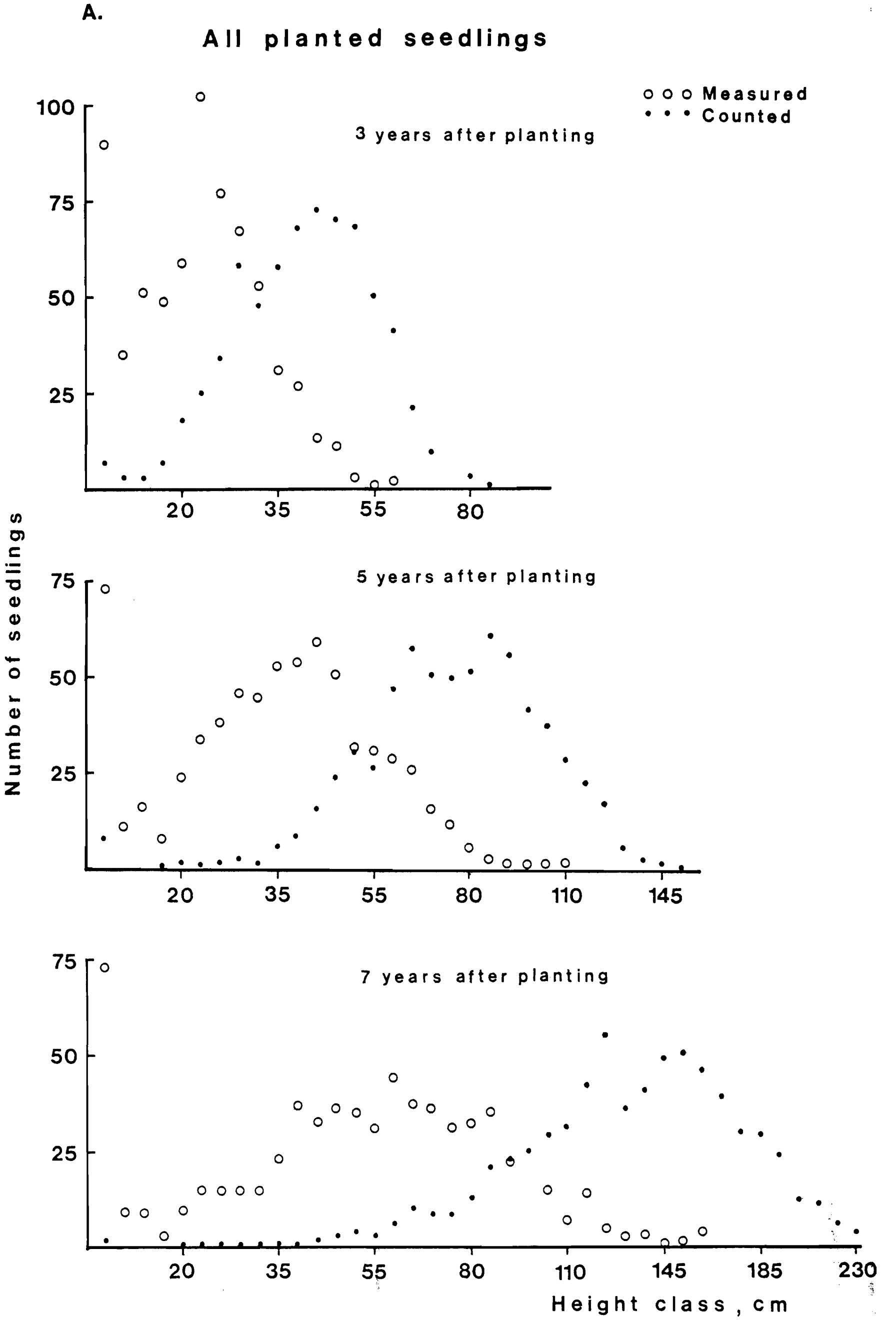

FIG. 5a—Calculated and actual height class distributions: **A.** for all seedlings.

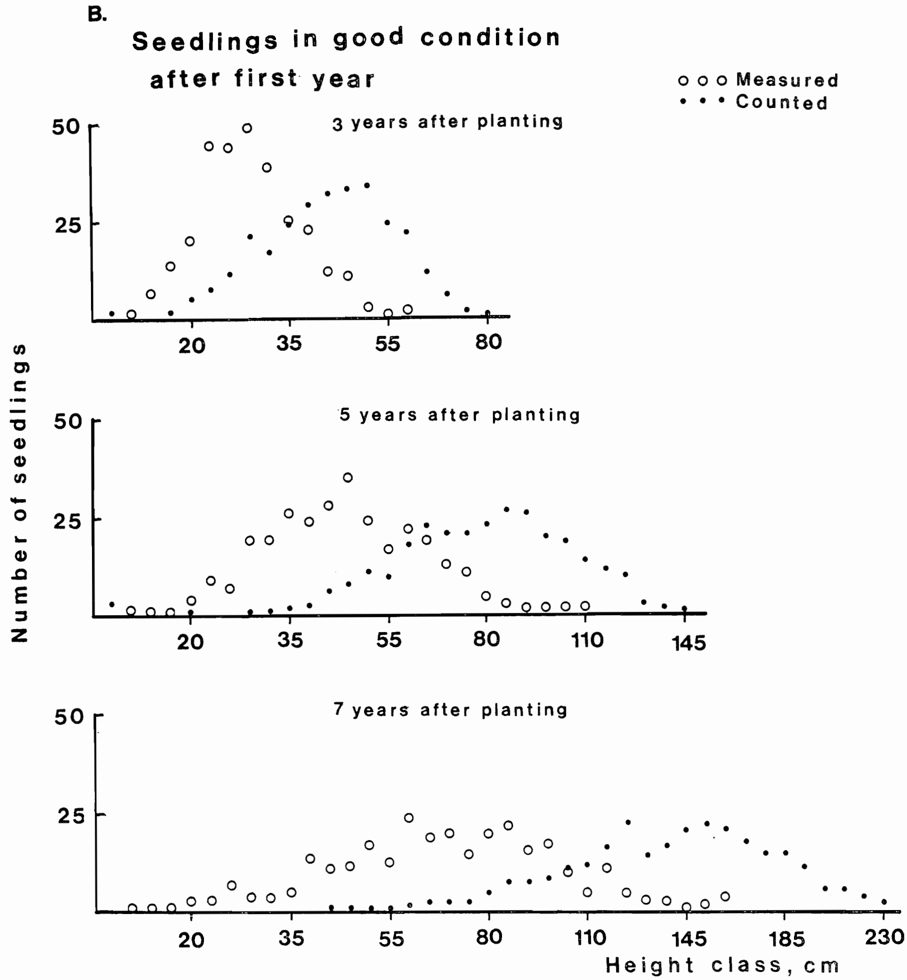

FIG. 5b—**B.** seedlings estimated as being in good condition after the first growing season.

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