CONCEPTS OF FOREST STABILITY AND FOREST MANAGEMENT

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Abstract

To realize its most important task, the perpetuation of forest use by the stabilization of the forest itself, forest management must have sound ecological foundations. A steady-state, equilibrium in species composition, resulting from unidirectional succession, is not acceptable as a parameter for the stability of the forest ecosystem. Its concept is based on the prevalence of internal control, whereas the frequency of minor and major disturbances, as well as the importance of chronic external influences characterize the forest as a relatively open system. With better results, the stability of a forest can be measured by its resistance to internal and external stress, its degree of resilience and the community control over energy-flow, hydrology and nutrients. Forest management is aware that forest stability is not a permanent state. Therefore silvicultural treatment must control the dynamics of change within limits, set by the physical environment and the biotic components of the forest. Each intervention is to be seen as a purposefully induced and willfully directed perturbation to stimulate and optimalize the internal mechanisms of selfregulation.

INTRODUCTION

Forest stability, as an ecological concept, refers to the forest as an object and deals with permanent factors, whose relative importance is variable in time and space. The economic concept of forest stability goes out from conjunctural and temporary aspects of forest use. It is therefore logical to give the object precedence over its use. As forest management and silvicultural interventions are judged by their functionality (L a m p r e c h t, 1976), they must be based on ecological reality.

FOREST STABILITY

The forest is a relatively open system, dominated by long-lived trees increasing in height, biomass and demands on space and energy with the passing of time. It is frequently subjected to disturbances, different in character, intensity and impact. They provoke complete or partial, acute or chronic forest destruction, causing modifications of site and environment. Perturbations can occur many times during the life span of the dominant trees (Mc B r i d e & L a v e n, 1976; H a s e, 1976; C o n n e l l & S l a t y e r, 1977), limiting their life expectancy (H o u s t o n, 1973; G a l l a g h e r, 1974 ; S p r u g e l, 1976 ; H e i n s e l m a n n 1981). Their frequency is reflected in the horizontal pattern of age-class distribution (S m i t h, 1946 ; S p u r r, 1965 ; H e i n s e l m a n n, 1973 ; O l l i v e r & S t e p h e n s, 1977) and the occurrence of homogeneous phases, also in tropical rain forests (H a r t s h o r n, 1978 ; T o m l i n s o n & Z i m m e r - m a n, 1978 ; G o m e z & V a z q u e s, 1981). They result from regeneration bursts (H u s e, 1963 ; L o u c k x, 1970 ; C o n n e l l & S l a t y e r, 1977) as a consequence of the release of space, the availability of seed at the right moment, sprouting, emergency of advance-regeneration and, eventually, planting. Selection is the strategy, adopted by nature, to meet the incidence of perturbation. It furthers the dominance of the most resistant species and individuals and their heaping in a relatively homogenized upper stratum, fully exploiting space and making maximal use of energy and resources at their disposal. The capacity of the forest to absorb destabilization resides in its potential to accumulate living and dead biomass, to immobilize temporarily CO_2, to store large quantities of water and to regulate the flow of nutrients and particulate matter (B o r m a n n & L i k e n s, 1979). Permanent social contacts induce dominant trees to adopt a habitus that, together with the formation of stability cells, increases their resistance to mechanical stress. Dominated individuals, useful to internal community structure, are protected by the upper canopy. The forest, as a functional system, is subjected to progressive and regressive processes, resulting in permanently changing compensation levels (O l - s c h o w y, 1971). The tolerance of the system is limited. The possibilities for restoration and recurrence after disturbance are determined by the degree of destabilization, the availability of suitable new community builders and the environmental changes brought about.

The recognition of the nature and consequences of disturbance implies the rejection of species composition as an absolute parameter for forest stability and of a relative steady-state equilibrium in species composition, produced by progressive control of the physical environment by the plant community. The unidirectional and predictable succession, leading to an unique climax with functional and structural characteristics (Whittaker, 1975) reflecting a particularly well-adapted species configuration as a consequence of uninterrupted evolution (Braun-Blanquet, 1964 ; Daubenmire, 1968) is a theorretical abstraction, requiring more concrete information on the mechanics of adaptation and adjustment, if applied to forest development. The degree of stability and the steady-state, corresponding to the climax concept of relay floristics, are therefore considered as rare (Connell & Orias, 1964 ; Huston, 1979 ; Woods & Whittaker, 1981) or made impossible by the frequency of disturbance (Frissell, 1973 ; Heinselmann, 1973). The rejection of the uniqueness of the climax situation is also implied in the early concepts on multiple floristic stability of Clements (1916) and Aubréville (1938).

In their search for a suitable definition of forest stability, Connell & Slatyer (1977) explored models of forest development based on inhibition, tolerance or facilitation as the driving force behind succession, but they found no satisfying answer. Neither the phenomena of resilience (Lewontin, 1968), persistence (Henry & Swan, 1974 ; Connell & Slatyer, 1977) or adjustment sufficiently explain the creation and nature of stability. They all refer to real, but partial aspects of development, linked with eco-physiological processes that should be analysed in a broader context of mutual interference.

Recent analysis follows, essentially, two lines of thought. The first still regards internal control as the decisive factor. This concept does not exclusively belong to theories on relay floristics (Clements, 1916; Egler, 1954, Niering & Egler, 1955 ; Marquis, 1967 ; Odum, 1969 ; Horn, 1974) but also refers to bio-energetic control (Bormann & Likens, 1979), considering the steady-state as the result of an orderly pattern of autogeneous development. The second school attributes more importance to the ability of a system to resist or channel destabilizing forces. It stresses the importance of energetic forest characteristics. (Woodwell & Sparrow, 1965 ; Drury & Nisbet, 1973 ; Sprugel, 1976 ; Bormann & Likens, 1979 ; Packman & Harding, 1982).

As basic conditions for bio-energetic stability Bormann & Likens (1979) put forward :

- The prevalence of production over losses and biomass destruction during the greater part of succession.
- Control of nutrients flow and movements of particulate matter, resulting in control over erosion and energy output.
- Control of the hydrological cycle, by the regulative effects of transpiration and water storage.

In this way a temporary or relatively permanent steady-state, with little variation in primary production and species content (S p r u - g e l, 1976) is attainable. Compared to preceding phases, it shows a decrease in gross and net primary production and a sub-maximal biomass level. The ratio of biomass to energy input is high (D r u- r y & N i s b e t, 1973). The ratio of production to biomass is decreasing. Gross production can equal respiration losses (W o o d- w e l l & S p a r r o w, 1965), bringing net production to a zero-level.

Although bio-energetic stability concepts consider large-scale disturbance as an important factor, they often do not pay enough attention to minor disturbances, which, by their frequency and spatial distribution can disrupt stability or prevent its creation (C o n n e l l & O r i a s, 1964; H u s t o n, 1979 ; W o o d s & W h i t t a k e r, 1981). To M a r q u i s (1967) catastrophes are even normal and necessary events, but this view is disputable.

T a n s l e y (1935), distinguishing between autogenic and allogenic disturbances, considers them as ever-present phenomena. They occur as continua of size and frequency. Sometimes they are so small or so infrequent that, on the scale of a single stand, the community seems to be relatively stable (C o n n e l l & O r i a s,1964 ; H u s t o n, 1979). They can be seen as a short-cut to succession (C o n n e l l & S l a t y e r, 1977). Disturbances are essential for recovery when imminent forest degradation is announced by generalized senescence. Disturbances are exogeneous and induced by external factors or endogeneous, resulting from tree-fall, competition and concurrence (L u t z, 1940 ; H u t n i k, 1952). The prevalence of frequent exogeneous disturbances is indicated by the occurence of even-aged phases and horizontal dispersion of age-classes, even in untouched forests (R a u p, 1938 ; L e i b u n d g u t, 1959, 1960 ; H u s e, 1963 ; C o n n e l l & S l a t y e r, 1977).

To O l l i v e r and S t e p h e n s (1977) disturbances are basic to the small- and large-scale structure and the age-class distribution in New-England forests. They accept an allogenic pattern of forest succession, whereas B o r m a n n & L i k e n s (1979) desemphasize exogeneous disturbance to attribute more importance to autogeneous phenomena.

Whatever the option, it remains a fact that perturbation is more relevant to species content than the relations within the community (R a u p, 1938). The area and intensity of disturbance determine the conditions for site colonization (C o n n e l l & S l a t y e r, 1977). They influence diversity, that peaks immediately after disturbance (S p r u g e l, 1976). The absence of perturbation has a homogenizing effect (P a c k m a n & H a r d i n g, 1982). Occuring continually and everywhere, disturbances are also frequent in tropical rain forests (S c h u l z, 1960 ; H a r t s h o r n, 1978 ; W h i t m o r e, 1978).

As disturbance sets the stage for succession and determines its course, the ability to understand succession depends upon the ability to model disturbance regimes by finding the right descriptors (V i t o u s e k & W h i t e, 1981). The impact of any disturbance on diversity depends upon its magnitude and intensity. If they cover lage enough areas, they promote gregarious resettlement and the appearance of even-aged phases of variable diversity under variable conditions (R a u p, 1938 ; H u s e, 1963 ; L o u c k x, 1970). Deblocking energy on a small spatial scale stimulates vertical diversity. Maximal diversity, on all levels, is nearly always obtained immediately after intense and frequent perturbation (H a c k & G o o d l e t t, 1960 ; M a r g a l e f, 1968 ; H a r p e r, 1969 ; D r u r y & N i s b e t, 1973) over not too large an area.

The assessment of the impact of disturbance on stability is directly related to the adopted scale of time and space (C o n n e l l & S l a t y e r, 1977) in connection with the intensity of perturbation (L e w o n t i n, 1969). If the disturbed area is large enough to contain all phases of forest development in a well-equilibrated spatial pattern, a state of general stability can arise (C o n n e l l & S l a t y e r, 1977), characterized by the presence of species with different metabolistic efficiency, good distribution of pioneers and tolerants and a nearly constant level of production (P a c k h a m & H a r d i n g, 1982). The time-space relationship and the assessment of the time factor are of fundamental importance for theoretical analysis and sound forest management.

Time as an active force, is greatly misunderstood or underestimated, although it helps to create the conditions for adaption and adjustment (O l s o n, 1958 ; M a r g a l e f, 1968 ; O d u m, 1969 ; H e n r y & S w a n, 1974). Modifications within the community are initiated by the sheer passing of time (O l s o n, 1958), changing individuals and populations. Time affects their relationship and vitality, changes their suitability as site occupants and co-determines their access to social positions in the community that depict their functional importance. During the greatest part of a forest generation, time promotes forest stability by favouring progressive dominance of tolerant species, who, in turn, increase the life-span of the forest and tend to bring unrest better under control. Time is needed for recovery. It promotes the shift from maximal exploitation of available resources for growth toward conservation and survival by better occupation of all soil layers within reach, increasing the stabilizing capacity of the forest floor and gradually optimalizing the flow of water and nutrients. In the course of time, the number of individuals decreases nearly continually, causing uninterrupted redistribution of energy and space, progressive concentration of biomass in selected dominants and advancement of tolerant components.
The temporary state of stability, thus created, brings about a certain degree of homogeneization, both in species and in forms. This relative homogeneity reduces, ultimately, resistance and sets the stage for change and the relief of one forest generation by another.

Better information on the potential for destabilization and more insight in biotic regulation, the hydrological system, the exchange of nutrients, the nature of conservative mechanisms and the value of reservoirs, have greatly influenced the actual concepts on forest stability. They help to better understand and to evaluate more adequately the natural strategies for growth, conservation, survival and regeneration. Multidisciplinary analysis allows to improve the classical models of succession or to complete the more concrete models of forest evolution of L e i b u n d g u t (1959,1960,1970,1978), C o u s e n s (1974) or B o r m a n n & L i k e n s (1977). They draw the attention of forest management and silvicultural treatment toward the possibilities of forest regulation and cyclical stability.

FOREST MANAGEMENT ON AN ECOLOGICAL BASIS

Stability, as conceived by traditional forest management, has no real ecological dimensions. Its origins lay in the wish to regulate wood production and to organize a predominantly monofunctional forest use. It aims at the creation and maintenance of a relatively static situation with regard to certain aspects of forest production, which are an emanation of social-economical development and therefore subject to continual change.

To maximalize timber reserves and material production, maintain the level of income flow and optimalize required services, management, in a general way, shortens the life span of trees and populations, modifies the species combination and, in doing so, relies on methods and practices that tend to decrease, permanently or temporarily, the intensity of the processes of self-regulation in the forest.

Recent developments, the relative economic wood scarcity (M a n t h y, 1977), the global incidence of destructive factors (A b r a h a m s e n et al, 1976 ; N.N. 1976) and the growing demand for polyvalent forests (N i e s s l e i n, 1980) have created a new set of conditions, to which forest management must adapt by optimal functionalization of the forest, creating modified time-space relations and defining acceptable levels of production.

The time factor

Forest management can increase forest stability by enlarging its time scales in different aspects.

Time, can be a stabilizing factor (M a r g a l e f, 1968), modifying individual trees in a way, favourable to general stability and provoking a decrease in the number of dominants. These developments enhance the forces of inhibition and favour species with a lower metabolic level, which are more resistant to biotic influences, due to slow growth and the higher density of their wood.

A broader time scale favours tolerant species, which, in the later phases of succession, are nearly always inconspicuously present as seedlings with a great power of energency, enabling them to fill the slightest gap and restricting the area of perturbation. Their presence makes recovery less hazardous and more predictable.

The choice of a broader time scale finds a technical expression in the lengthening of rotations and regeneration periods. Such a choice permits a better organization by planned spreading of interventions. It allows to construct horizontal patterns of distribution of age-classes, favourable to general stability (D a u b e n m i r e, 1968) and corresponding to widely found situations in virgin forest (R a u p, 1938, 1964; L e i b u n d g u t, 1945, 1959, 1960, 1978, 1982). Whether these even-aged phases will be homogeneous or mixed depends upon the area they cover : The impact of the area and intensity of cutting and of spontaneous perturbation are quite comparable. Therefore the relation between the scales of time and space should be kept in mind, when making the inevitable alternative choice between stability in time or in space as suggested by V a n L e e u w e n (1966).

Stability in time is linked with continual changes in space. By extending the life expectancy of trees, the rotation and the period for recovery after disturbance or cutting, the area, annually coming up for regeneration, is proportionally restricted. By dividing this area farther up till it corresponds but to the space of a single tree-crown projection, a small group or a single treefall, the stage is set for continual change, nearly uninterrupted regeneration, increased local unrest, vertical stratification and dominance of low metabolistic tree species.
If, at last, the regeneration period equals the rotation in length and the latter is no longer defined, a typical forest pattern arises :

a. On the broader space-level a state of general stability is created, characterized by constant annual increment or net production, constant, although sub-maximal growing stock or biomass with respect to site and present species, constant number of individuals in each stratum and increased vertical stratification.

b. On the local level, however, a mosaic of developmental phases arises, bearing the aspects of the prolonged crash, used by B o r m a n n & L i k e n s (1977) to characterize the transition phase.

If stability in space obtains priority, the scale of time must be drastically reduced, the regeneration period shortened and, in extreme cases (clearcutting followed by reforestation), brought back to a single year. Consequently the annual regeneration area grows la ger. If its further subdivision into smaller regeneration units is not undertaken, a forest pattern with following characteristics arises :

a. Horizontal distribution of age-classes, each covering an equivalent area. Under extreme management conditions the number of age-classes equals the number of years in the rotation.

b. Increasing homogeneity of the basic units, dominated by less tolerant species with a lower degree of metabolic efficiency.

c. Absence of stratification and partial loss of control over waterflow and nutrients, making recovery after disturbance or cutting more difficult and hazardous.

Such a situation can only be secured for a short time. It is easily disrupted by exogeneous perturbation or the acute need for cutting, due to favourable market conditions. As long as spatial stability exists, a constant biomass or growing stock, combined with nearly maximal production or increment is assured, but this period of stability is restricted. The influence of this system on site conditions is still under discussion.

Reasonable forest management must exclude the disadvantages of both alternatives. Therefore it has to make a preliminary choice of species and their combination in a desirable pattern of horizontal and vertical forest structuration. It must create an equilibrated relation between time and space, restricting the length of the regeneration period to give each elementary regeneration unit sufficient space. Final choices must give due respect to ecological considerations.

The level of production

Production and productivity are time functions (M a r g a l e f, 1968). They are not correlated with diversity (D a u b e n m i r e, 1968; O d u m, 1969; W h i t t a k e r, 1975). Translating ecological thought into term of forest management, this would mean that aiming at maximal increment (= production) or growing stock (= biomass) necessitates the fixation of the forest in a situation below climax, accepting a certain degree of homogeneization while recognizing the potential danger of structural degradation.

Aiming at maximam current increment (CAI-maximal net production) or at maximal mean increment (MAI-mean net production) requires, on the other hand, a severe reduction of the time scale with ecological consequences. The same applies to the acceptance of " the forester's maturity " (C o u s e n s, 1972 ; P a c k h a m & H a r d i n g, 1982), situated at the point where the CAI and MAI-curves cross. It supposes exploitation before physical maturity is attained and does not correspond with sound economic thinking, taking only volumetric development into account and not real value production.

For some time it was thought that sustained yield could give an ecological dimension to forest management, but to K r e m s e r (1973,1975), it is only a principle for equilibrating the bio-ecological/technico-economical duality of silvicultural thinking. R a u p (1964) rejects the idea and its development by G o u l d (M a n t h y, 1977 cit.) because it equates a closed economy, based on scarcity, certainty and stability with a self-perpetuating climax. B u r c h (1979) means that sustained yield is derived from social history and not based on a biological principle.

S p e i d e l (1971) considers it as a social-ethical obligation and for L e i b u n d g u t (1973) it is the consequence of planned direction of forest development. K r e m s e r (1973) traces its origin to the wood-scarcity of the 18th century, when it was considered a " bonum commune ", subsequently reflected in the opinion of G a y e r (1889) that sustained yield is a measure to protect the production apparatus. All these interpretations relate sustained yield with forest use and material production. They consider it as a postulate for well-ordained (technical) management (S p e i d e l, 1971).

To give an ecological foundation to the determination of the level of production it seems advisable to go out from the bio-energetic characteristics of forest succession and to bring the basic ideas of O d u m (1969) and the deductions by D r u r y & N i s b e t (1973) to a logical conclusion. This view puts forest management before an alternative choice between two strategies and their concrete expression in a production model and a conservation model of management with predictable characteristics (Tab. 1).

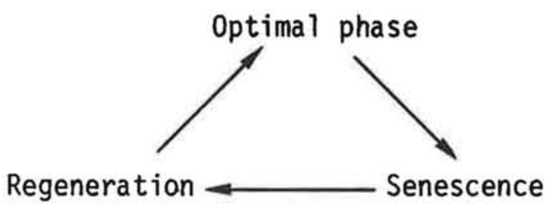
Tab. 1. Fundamental characteristics of management models based on succession analysis by O d u m (1969), D r u r y & N i s b e t (1973) and B o r m a n n & L i k e n s (1979).

Characteristics	Production model	Conservation model
Diversity (species and forms)	Reduced	High potential
Structural stratification	Reduced	Very high
Pattern of mixture	Horizontal	Vertical
Specialisation in site occupation	Rather low	High
Mineral cycle	More open	Rather closed
Internal regulation	Restricted	High
Hydrological control	Restricted	High
Homeostasis	Low	High
Biomass (=growing stock)	Very low – very high	Submaxiam level
Production/biomass	High to medium	Medium to low
Production/respiration	Rather high	Rather low
Life cycle or rotation	Short	Long to undefined
Orientation of selection	Quantity	Quality
Material production	Principal objective	Consequence
Net production(=increment)	Rather high/variable	Medium but constant
Value production	Restricted	High
Regeneration period	Short	Long
Regeneration unit	Large	Small
Forest type	Rather mono-functional	Polyvalent

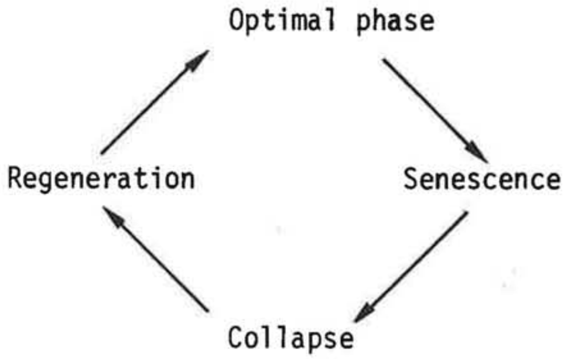
The production model serves short range objectives in the field of material production. It leads to exploitation before full maturity and before the end of the optimal phase (L e i b u n d g u t 1973), the aggradation phase (B o r m a n n & L i k e n s, 1977) or the building-up phase (C o u s e n s, 1974). It leads to clearcutting systems,monofunctional forest use, short regeneration periods and large regeneration units dominated by less tolerant tree species. Recovery or reorganization covers a great part of the rotation.

The conservation model corresponds to systems based on selection and group regeneration. It adopts a larger time scale, avoiding absolute clearcutting over large areas. Regeneration, dispersed in time and limited in space, is induced before the forest starts to collapse and senescence becomes general. Trying to avoid entropy, loss of control over waterflow and nutrients, decrease of selfregulation, it endeavours to realize cyclical stability as described by L e i b u n d g u t (1970).

To this end it tries to realize the cycle



avoiding



and especially

Optimal phase → senescence → collapse → degradation → resettlement

Functionalization

Optimal forest functionalization is realized by a coherent set of measures to bring or keep the forest in a state, which preserves desirable functions and services, but without causing forest degradation or a loss of stability and a decline in productivity. In this sense functionalization is to be given priority over material production (M a n t e l 1973). It does not imply the adaptation of the forest to human needs, bur prefers forest use and management " sui generis " by promoting specific or idiotropical functions (F l e m m i n g, 1969). The elaboration of priority series is thought to be impossible or unadvisable (L a m p r e c h t, 1976), because conforming to actual demands promotes continual forest transformation, that, in the end, endangers the forest and its functions. To bring functionalization permanently under control, a long-term function-plan must be drafted (B a u m g a r t, 1974). It serves to prevent pluralistic use from exceding the carrying capacity of the forest. The rejection of the priority principle and the acceptance of economic, social, ecological and cultural function-groups (V a n M i e g r o e t, 1976) have created misunderstanding. Most discussions are centered around the acceptance or rejection of functional pluralism (K r e m s e r, 1973 ;1977) or the difference in opinion on the relationship between forestry and technology (W o h l f a r h t, 1971). Protagonists of the " Wake Theory " consider non-material production as secondary (D i e t e r i c h, 1950), give undisputed priority to material production and income flow (S p e i d e l, 1971; P o l l a k, 1971) and view economic use as a precondition to forest conservation (B o e h m cit. S c h u m a c k e r, 1972). The uneasiness, caused by the rejection of economic priority, is a consequence of the conflict between " old " .and " new " objectives (M a n t e l, 1973). It is an expression of fear, to be reduced by research and through analysis of forest management.

SILVICULTURAL TREATMENT

The equation of silvicultural treatment with exploitation and harvesting reflects a profound misunderstanding of its real aims. Because it is logical to give the object priority over its use, silvicultural treatment is responsible for the protection of a fairly fragile system used by man. At the same time it is supposed to warrant the permanence of material pro duction and non-material services under well-defined restrictive conditions. The ecological foundations of treatment reside in the knowledge of the forest ecosystems and its functioning. It makes use of the results of ecological research and their appropriate interpretation. Treatment must be permanently aware that it not only manipulates the forest structure, but also interferes with self-regulating processes and the reserve function of the forest, simultaneously modifying its physical environment.

The nature of intervention

To realize its primary objective, the creation of a state of relative forest stability with structural, functional and developmental aspects, silvicultural treatment uses the potential of the forest for self-regulation (Leibundgut, 1973). It to increase individual and collective resistance against external influences and channels the forces of internal stress. It essentially creates order (cfr. Odum, 1969), promotes the shift from entropy to negentropy (Bormann & Likens, 1979) and maintains or restores functional relationships (Olschowy, 1971), aiming at maximal compensation between stabilizing and destabilizing forces. The parameters for its success, also from an economical point of view (Lamprecht, 1976), are the permanence and the degree of functionality it is able to create and to maintain.
Forest treatment is essentially based upon the possibilities to transform the ecosystem, to direct structural and functional development and to influence biological cycles (Kremser, 1973). It claims the right of alternative choice, rejects the uni-directional character of internally controlled succession and recognizes the reality of frequent and predominantly exogeneous perturbation. The knowledge that the presence or disappearance of species, their pattern of mixture, their social and functional position is partially determined by the time-factor and mainly by external forces (Hack & Goodlett, 1960 ; Harper, 1969; Drury & Nisbet, 1973 ; Marquis, 1973), leads to the concept of intervention as a directed external factor, used, among other things, to control the impact of spontaneous external influences. In this view silvicultural intervention takes the double aspect of a willfully induced, anticipative and directed disturbance with predictable consequences and it is, at the same time, a device to prevent unwanted perturbations or to absorb the shock they cause.
As the essence of ecosystem development is the control of destabilizing forces, treatment must pay attention to the potential for destabilization of all input. (Bormann & Likens, 1979 : radiation, water, gravity, wind). These forces must be channelled in time to reduce their negative effects and make them work for the accumulation of biomass, dead and living, which helps to stimulate biological processes and creates stability by increasing control over internal regulation, especially by using transpiration as an essential mechanism for conservation. To this end, treatment must be well aware of the intrinsic character of available species, their actual life history, the particularities of the site and its relationship to the living community.

The aims of treatment

The main problems of forest treatment are the control over the driving forces of succession, the minimalization of all output, the promotion of internal stability and the increase of resistance against negative influences so as not to cross the limits of tolerance.

The creation of community stability starts with the promotion of the stability of individuals, species and populations, leading to the concept of early individualisation of treatment. In addition, community stability can be favoured by the concentration of site occupation (R a u p, 1964), but even under excellent conditions, it is never permanent in time and space.
The promotion of stability requires silvicultural choice in different fields. The first choice concerns the developmental phase, judged most suitable for temporary fixation, or the definition of the nature and the level of stability to be realized and maintained as long as possible. Such a state nearly never corresponds with a climax situation or a phase with maximal diversity (H a c k & G o o d l e t t, 1960 ; H a r p e r, 1964 ; D r u r y & N i s b e t, 1973 ; V a n M i e g r o e t, 1980 ; B o r m a n n & L i k e n s, 1979). Its maintenance requires subtle intervention, especially if the chosen state does not correspond with maximal developmental stability, as is often the case.
The choice of species, their combination and the induction of their social and functional status is equally important. The differences between species in morphology, life expectancy and tolerance define the length of the actual forest generation, the degree of resistance against external perturbation, the conditions for ultimate regeneration and thus for global stability.
A last choice has to do with the apropriate patterns of time and space on the assumption that reduction of the scale of space and extension of the time scale, separately or, still better, in equilibrated combination, lessen unrest. Their sensible manipulation helps to reduce the impact of destabilization, optimalizes self-regulation and promotes redistribution of energy and access to resources. The principal objectives of redistribution are maximal use of the growth potential of the most suitable species and individuals, favouring of highly qualified dominants and protection of less vital, but functionally valuable components.
SIlvicultural treatment finds inspiration in the phenomena of natural selection, resulting in the numerical decrease of species and individuals in the course of time, the continual redistribution of biomass and the modification of mixtures in favour of long-lived tolerant species.

The strategy of silviculture

The forest community undergoes continual change. These modifications must be reflected by the versatility of forest treatment, whose quality is to be judged by its ability to recognize changing patterns and to find a sensible response to them. This concept corresponds to the basic idea of L e i b u n d g u t (1970) about the uniqueness of each forest situation and the need to study its genesis to formulate concrete objectives, chosen among a number of plausible alternatives, and to define the best course of intervention along the following lines :

a. Constant redistribution of the bulk of living biomass over a decreasing number of trees, those with the highest vitality in case of unrestricted natural selection and the most suitable components in well-treated forests.

b. Continual shift of mixtures in favour of long-lived and slow growing tolerant species.

c. Concentration of a restricted number of species and individuals in the upper canopy, promoting relative homogeneity, that reflects the opposition of R a u p (1964) to the linking of maximal stability with stand irregularity, high diversity and a geometric age-class distribution.

d. Temporary decrease of the drive toward change (M a r g a l e f, 1968).

Treatment can control these modifications, using analysis of the succession models of L e i b u n d g u t (1970; 1978; 1982), B o r m a n n & L i k e n s (1979) and C o u s e n s (1974). They all demonstrate the need to limit reorganization in time and space as it reflects loss of control and biotic regulation. Recovery must be aided by all means, principally by preparing forest regeneration in time, rejecting the idea of structural fixation and promoting cyclical stability before general senility sets in.
The continuity of stand treatment can be assured by following the gradual modification of basic strategy in natural forest development over the following sequence :

a. Promotion of stand regeneration, global care for regeneration and initial regulation of mixture to lay the foundations for structural patterns and species composition. This kind of treatment is undertaken in the period between first resettlements or emergency and primary crown contact = Reproductive strategy.

b. Promotion of development toward maximal biomass and P/B ratio, improvement of internal control and resistance against allogenic and autogenic stress by the regulation of growth, selection and redistribution of space and energy. This phase ends with functional stratification. The period can be divided into three subperiods, delimited by successive culmination of growth in height and stem diameter. The degree of change brought about is determined by the frequency and intensity of thinning. = Exploitive growth strategy.

c. Maintenance of a temporary state of stability, characterized by relative homogeneity of the upper canopy and a decrease in biomass, increment and P/B ratio. This period ends with the culmination of volumetric increment. = Conservative strategy.

The background of silvicultural systems

Repeatedly the question is raised to what extent silvicultural systems can be accounted for from an ecological point of view. In some cases they can be traced to real concern for forest conservation. Often they are based on observation and interpretation of natural phenomena. The basic systems, with their typical characteristics, are replicated in nature, even in untouched forests.

Clearcutting (Kahlschlag), whether over a small or a large area, corresponds to minor or major disturbance, accompanied by forest destruction (wind, lawines, fire, snow, floods). Whether spontaneous or planned, the consequences are identical : loss of biotic regulation, acute entropy, release of water and nutrients by the forest floor, initiation of a long period of recovery with relatively high respiratory losses and a low level of net production, due to incomplete occupation of the site and the characteristics of juvenile growth. The release of space and energy initiates a strong homeostatic response, that activates reproduction (B o r m a n n & L i k e n s, 1979) with a direct impact on diversity and species.

Organized clearcutting has the same effect as a disturbance, but can keep the situation better under control, by shortening the period of recovery, consolidating the first migrations, directing the combination of species and creating a higher potential of stability by artifically adding more tolerant species.

Group regeneration (Femelschlag), eventually with temporary maintenance of a reduced upper canopy, often occurs in nature. Even in tropical rain forests group regeneration is common (C o d y & D i a m o n d, 1975 ; W h i t m o r e, 1978 ; T o m l i n s o n & Z i m m e r m a n n, 1978; G o m e z & V a z q u e s, 1981), large clearings are not exceptional and openings in the canopy are sometimes made with a frequency of 80-90 years. If treefall produces small clearings, the gap is rapidly filled by emergent individuals, pre-regeneration and new seedlings, issued from burried-seed. If the clearings are large and uncoverd, colonization by rapid growing nomads (S c h u l z, 1960) is to be expected.
It is basic to recognize that the area, liberated by a single treefall, is considerable larger than the crown projection of the fallen tree and roughly corresponds to S_t = 0.875 D.h. (h = tree height ; D = crown diameter).
In the forest under management, accidental treefall is replaced by planned removal of trees and regeneration follows the same pattern as in nature. The system implies, however, a more orderly dispersal of groups in space and time and a well ordained progress. Variations in size of the group and regulation of the density of the remaining canopy are used to direct the combination of species and to control growth. By creating an optimal time-space relation, it is possible to increase actual and potential forest stability.

Regeneration under the cover (Schirmschlag) of a restricted number of older trees and over a fairly large area, either as the consequence of mild perturbation in untouched forests or induced by series of preparative cuttings, reduces destruction, releases space very slowly and creates a close relationship between the remaining dominants and the new generation. Good control over biogeochemistry is retained. The cover favours tolerant species by promoting their emergency and inhibiting the growth of nomadic emigrants. Change is slowed down as in a pre-climax situation (M a r g a l e f, 1968) and forest stability is positively influenced by the presence of tolerant species and relative homogeneization. Individual growth response is reduced. Irregular density of the upper canopy, whether accidental or created systematically, leads to group regeneration with dominance of tolerant species, where the cover is maintained, and bursts of regeneration of early succession species, where the soil is locally uncovered.

Although strip regeneration (Saumschlag) is a transition between clearcutting, group regeneration and regeneration under cover, it reveals specific characteristics. It corresponds to a natural model of wave regeneration as a consequence of chronic wind damage (S p r u g e l, 1976). Regeneration progresses regularly, also under natural conditions. As a system it allows to create a state of uninterrupted regeneration based on cyclical stability.

The selection system (Plenterung) maintains a structural forest pattern, considered by a number of ecologists and foresters alike, as approaching an ideal steady-state resulting from spontaneous forest development under optimal conditions and therefore to be perpetuated indivinitely.
The energetic characteristics of these uneven-aged, irregular and diversified stands are typical for a pre-climax or a post-climax situation as seen by O d u m (1969) or defined by M a r g a l e f (1968) :

- Constant biomass (= growing stock) because respiration losses equal gross primary production.

- Submaximal but nearly unchanging net production. The release of space and energy by dead adults promotes continual regeneration and a relatively high degree of diversity, reflected in species combination and a geometric type of d-class distribution.

- Low ratio of production to biomass.

General dispersion of local regeneration and frequent emergency correspond to a pattern of continual, but localized slight disturbance, resulting in a vertical forest structure and a pattern of individual horizontal mixture, determined by the limited release of space for regeneration.
The selection forest is comparable to the transition phase or steady-state phase as described by B o r m a n n & L i k e n s (1979) : it is the result of prolonged crash. The structure of the selection forest is undoubtly a time-function. It requires perpetual induction of minor disturbances by the practice of conservative cuttings, limited to the harvest of increment so as to maintain a constant level of growing stock (= biomass). The

fixation of the structure of the selection forest, which is not to be considered as a prototype of over-all stability (L e i b u n d g u t, 1945, 1959, 1960), makes permanent intervention necessary and requires the definition of a well-thought pattern of time and space, although such a notion is rejected by its most convinced promotors (A m m o n, 1951 ; D a n n e c k e r, 1950 ; P o c k b e r g e r, 1950).

THE ECOLOGICAL BACKGROUND OF TECHNICAL INTERVENTION

If management considers the forest as a complex and fragile ecosystem and defines intervention as a purposefully induced perturbation to obtain a higher degree of stability by the choice of components and the promotion of their growth, as well as by furthering individual and collective resistance to spontaneous external disturbances,it is necessary to give intervention an ecological background and let natural processes inspire the elaboration of suitable techniques.

A thorough scrutiny and comparison of natural processes and technical intervention to study their impact and evolution, promotes insight in both, natural forest succession and provoked change. It is essential to keep the forest in good condition to let it serve human interests.

Homogeneization

Forest management is often reproached to favour extreme homogeneization in order to obtain quick results with fast growing species. Although this is true and the corresponding management procedures are questionable in many respects, it does not permit to condemn homogeneity as a matter of principle. Under natural conditions homogeneity is not exceptional. Major disturbances on a larger spatial scale are often followed by bursts of regeneration of a single pioneer species, available at the right moment and site. This is particularly the case in regions where good seed years are widely spaced.

Natural homogeneity is mainly the result of good synchronization of growth with cosmic phenomena on a large scale. It is typical for extreme sites where growth is slow by lack of sufficient resources and only a restricted number of species flourish. But also large areas of rain forests in Africa, South- and Central-America and SE.Asia are dominated by a single species (P a c k h a m & H a r d i n g, 1982) and homogeneous or uniform phases are found on a large scale in european virgin forests (L e i b u n d g u t, 1945, 1959, 1960,1970, 1978, 1982 ; H u s e, 1963).
Homogeneization can have two essentially different causes :

a. Spontaneous or artificial forest destruction over a large area, followed by quick regeneration, due to the invasion of a single species or by afforestation under equivalent conditions.

b. The egalizing effect of biomass accumulation and a decrease in the number of species and individuals, concentrated in the upper canopy, promoting the role of tolerant species (M a r q u i s, 1967) and inhibiting the growth of eventual migrants. This situation, corresponding to the maintenance of an older stand with a dense canopy, is also typical for the later phases of natural succession when unrest and diversity decrease as stability increases in a reversal of conditions occurring immediately after perturbation (H a c k & G o o d l e t t, 1960).

The idea that complex structures can be more fragile and relatively simple systems dynamically more robust (M a y, 1978) should be retained in assessing the merits of diversity and homogeneity or judging some aspects of forestry practice.

Afforestation and reforestation

If disturbance is a short-cut to succession (C o n n e l l & S l a t y e r; V a n M i e g r o e t, 1979), artificial restoration of the forest stimulates succession, eliminates undesirable phases and shortens the period of reorganization. It allows to regain quick control over biotic regulation by making good use of available resources. It is able to create a far better pattern of horizontal distribution of species and age-classes as produced by accidental disturbances. From the study of relay floristics (P o u n d & E g l e r, 1953 ; M a r q u i s, 1967 ; O d u m, 1969 ; M c C o r m i c k, 1968 ; cit. D r u r y & N i s b e t, 1973 ; H o r n, 1975 ; W h i t t a k e r, 1975), reforestation technique learns the optimal use of space. The fact that pioneer species are often a deterrent to development toward a higher degree of community stability and that their destruction nearly always stimulates evolution (M c C o r m i c k, 1968 ; D r u r y & N i s b e t, 1973), is sufficient justification for the shortening or abolition of the early stages of resettlement.
From the facilitation model of C o n n e l l & S l a t y e r (1977) can be learned the usefulness of the protection of more long-lived species by a cover of early succession species in the early stages of migration. In the same order of thought, some afforestations must be seen as pioneer stages, useful to shorten succession and prepare the site for more valuable spontaneous migrations or artificial introduction. On the oter hand, plantings can become complementary to migration.

The study of migration, emergency and the importance of burried seed can influence re- and afforestation technique considerably :

a. By adequate spacing during planting, sufficient space and resources remain available for complemantary migration and spontaneous resettlement.

b. Actual plantings are but part of a potential population. Intricately mixed stands can be created by clever combination of spontaneous processes and artificial intervention.

In this conception, reforestation becomes part of a strategy of forest restoration.

The choice of species

Under natural conditions the species content of a forest ecosystem and their social and functional position is neither accidental nor predestined. In a broad consensus, species content and initial mixtures are considered as ecological phenomen more related to disturbance and species availability than to internal control (R a u p, 1938 ; D r u r y & N i s b e t, 1973). It is widely accepted that maximal species diversity occurs in the early stages of succession (H a c k & G o o d l e t, 1960 ; H a r p e r, 1969 ; D r u r y & N i s b e t, 1973 ; B o r m a n n & L i k e n s, 1977).
Early succession species (pioneers) and late succession species (tolerant species) often appear simultaneously or within a short distance in time (M a r q u i s, 1967). In the course of succession tolerant species progressively dominate the patterns of mixture, increasing stability and, inversely, decreasing diversity. These facts in nature justify the principle of the choice of species by forest management and its acceptance as a normal task of forest care. Silvicultural intervention as an induced disturbance, creates the conditions for regeneration at the right time and place, taking species availability into account. It can prepare the site for colonization or restrict its action to the uncovering of inconspicuously pre-existant spontaneous regeneration.

The combination of species is regulated and the actual, as well as the future degree of forest stability determined by the choice of regeneration space, the rate of uncovering and the progress of release. The situation at maturity greatly depends upon the control of regeneration and the early, but continual regulation of the relations between species, as well as between species and site. Variations in the nature, the intensity and the phasing of silvicultural intervention will be responsible for structural variability, corresponding to the view on stability held by A u b r e v i l l e (1938) and others (C l e m e n t s, 1916 ; L e w o n t i n, 1969; O l i v e r, 1978).
With full knowledge of the origin and the evolution of the combination of species in untouched forests, silvicultural treatment can not be denied the right of choice, corresponding to alternative developments in nature.

Particular aspects of intervention

Early intervention in forest development is based on three phenomena :

a. The quick decrease in the number of species and individuals, due to external influences and increasing internal stress.

b. The precocious loss of specialization in site occupation.

c. The early culmination of diversity in species and forms, typical for the early stage of succession.

Timely intervention can make maximal use of the opportunities for selection to lay the foundations for stable structural patterns.

At the moment of the first interventions, treatment can and may have a well defined course of succession or events in mind. It tries to anticipate spontaneous development by directional redistribution of space and resources. It replaces natural selection, favouring the most suitable elements. In the course of time the protection against external influences is gradually replaced by the regulation of internal relations as a main objective of treatment.

As ultimate stability is more determined by the relations between individuals as between species and because a community is as stable as its components (H o r n, 1974), individualization of treatment must be undertaken as soon as possible. It has an economic and an ecological dimension. The main objective of individualization is the maximal use of the potential of each tree to serve the community and the interests of management for an undefined period. Therefore trees are removed at any time to promote the growth and development of the more valuable remaining elements.
Thinning stands is but anticipating natural phenomena, while retaining full control over the circumstances of disappearance.

Each disturbance creates a shock in the forest ecosystem : each intervention has the same effect. To assuage the impact of shock, the intensity of intervention and the change it provokes must be reduced. As a compromise between the need to reduce shock and the necessity to obtain permanent control over continual evolution and uninterrupted development, the interval between interventions must be reduced.
The continuity of treatment is best served by mild interventions at a short interval, permitting treatment to follow evolution and to control change. Repeated intervention at short intervals is replicated in nature by frequent minor and major spontaneous disturbances. In Bavaria 1/4 to 1/3 of annual cuttings are a consequence of damage (W e i n - z i e r l, 1974); in this region 1/3 of the forests are destabilized and 1/3 are in a labile condition (K o e s t l e r, 1950). G a l a g - g h e r (1964) reckons with 7 to 15 heavy storm-situations pro century

in Ireland between 1608 and 1974. During the last 700 years heavy wind damage occurred with an average interval of 12 years in Schleswig-Holstein (H a s e, 1976). Forest fires show a frequency of 10-12 years. (1897-1904) to 20 yrs (1905-1965) in the pine stands of the San Bernardino Mountains in California (M c B r i d e & L a v e n, 1976). In Yellowstone National Park fire-frequency varies between 32 to 70 years (H o u s t o n, 1973), W e i n (1978) notes an average interval of 5-12 years to conifers.
Between 1965 and 1971 no less than 48.995 forest fires occurred in the well-controlled forests of the 6 E.E.G. countries, destroying 1.6 % of the entire forest area and covering an average of 10 ha each. (V e r s l y p e, 1982).
About 20 % of annual exploitation is due to snow damage in Austria (K o h l, 1980) and between 1910 and 1961 great damage was caused in the F.R.G. by 5 catastrophic winters (K ö h l e r, 1973).

It is evident that, with such examples in mind, the removal of trees by sensible treatment is a very mild disturbance, precisely intended to increase resistance against external influences and stress.
Planned tree cutting serves forest stability as it consciously favours longlived species and the most resistent components. By not only caring for individual growth, but also for functional structuration, a more general state of stability is created. By the orderly removal of trees in the forest, fairly well predictable phenomena are activated : release of space and energy — promotion of emergency, migration and germination of accumulated seed — increase of floristic diversity (species and forms) — enrichment of ecosystem by promoting heterogeneity — increase of faunistic diversity — increase of global ecosystem diversity.
Silvicultural intervention can interfere with and act upon each of these phases by making use of its opportunities for choice.

Far from being a destructive factor, sound forest treatment, executed under optimal conditions and permanently controlled, can, with full knowledge of and respect for ecological relationships, be viewed as an means to promote a higher degree of stability in most forests.

CONCLUSIONS

The unequivocal definition of forest stability and the correct assessment of its nature require the use of the right descriptors and a multidisciplinarian approach. It is necessary to arrive at an integral concept, avoiding partial analysis, that gives too much importance to particular aspects of forest development and isolated phenomena.
To understand better the real nature of disturbance and destabilization, more coherent research is needed on eco-physiological processes, going on in the forest, in a broader context of mutual interference. Due attention is to be paid to the time-space relation and more information required on the character and working of stabilizing and destabilizing forces, as well as on their impact on biotic regulation.

It is equally important for ecological research to understand the real motives of forest management and silvicultural treatment. They are important factors, not only in forest development, but also as methods for stabilizing the forest ecosystem, constantly endangered by manyfold and far reaching exogeneous disturbances.

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