THE NATURE OF FOREST DEGRADATION

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INTRODUCTION

Forest degradation has developed into a problem with global dimensions. It is often the result of historical evolution, leading to use or abuse of the forest by man. Sometimes, its origins can be traced to purely natural causes and to minor or major catastrophes, not directly involving bad human conduct.

Misunderstandings on the real nature of forest degradation persist, creating situations of stress and confrontation between practical foresters and theoretical ecologists. Even in the fields of ecology and nature conservation no unanimity exists concerning the interpretation of stability loss and functional decline of the forest.

The Reykjavik Symposium of 1977 on the breakdown and restoration of ecosystems (Holdgate & Woodman,1978) offered an opportunity to confront the views of leading ecologists with contemporary thought on forest degradation.

1. THE DEGRADATION CONCEPT

1.1. The forestry view

Most foresters use 'forest degradation' as a more or less intuitive concept, based on experience and empirical observation. It implies a certain amount of unwelcome change in the forest, brought about by external influences and severely reducing its optimal functioning, quite often beyond repair. In some instances it is perceived as the result of inevitable social and historical development. Such a deterministic approach makes the forester powerless to react adequately, if no concrete recommendations are formulated to this end by forest policy.

The reduction of the number of (valuable ?) species, textural decline due to an abnormal decrease in the number of trees and structural modifications, reflecting unfavorable alterations in the relative position of the forest components, are usually recognized as the main physical and visual characteristics of forest degradation. An unequivocal definition of the acceptable outer limits of change, beyond which forest restoration, either spontaneously or by payable technical intervention, has no fair chance to succeed, is rarely given. Considerable loss of material production and productivity, exceeding the probability of recovery within a reasonable time, is nearly always considered as the ultimate parameter for degradation.

Such an approach, with undeniable economic and technical undertones, may be useful for practical purposes and as long as the forester acts independently and in relative isolation. This is no longer the case, given the increasing plurality of forest use, the multiplication of real and potential aggressors, the impact of repeated external perturbations, as well as the growing interest of conservationists and the public at large. The maintenance of the forest in stable condition and a good state of health to prevent further environmental deterioration, mainly feared for its ecological, biological and social consequences, has become a common requirement.

Forestry should pay more attention to the ecological dimensions of the forest and of forest degradation. A broader and more holistic view on the forest ecosystem and its multiple functions is highly desirable. The task of forest management must be enlarged.

On the other hand, it is evident that direct human intervention is not always the only cause, in some instances even not the principal cause of forest degradation. Indirect human action, provoking severe environmental modifications with immediate repercussion on tree growth and forest development, and acute or chronic perturbations of forest communities by natural agents are, at least, equally important.

Lack of correct interpretation of natural disturbances includes inadequate understanding of (forest) community development (Veblen, 1985). From a silvicultural point of view, it leads to erroneous prediction of the most probable response of the forest to treatment and human interference.

Due to the considerable life expectancy of most forests, two fundamental patterns in forest stand development are to be reckoned with.

The <u>autogenic pattern</u> develops as a consequence of

- local release of more or less space,
- relief or intensification of internal stress on a variable scale,
- individual tree growth,
- evolution of populations and sub-populations,
- micro and meso-modification of ecological conditions,
- increasing control of the biocenosis over the site.

These processes occur separately or simultaneously. Their synergetic relationship is evident. The pattern they build, dear to classical phytosociological theory, corresponds to the model of succession and community development as formulated by Odum (1975) and Whittaker (1975).

The <u>allogenic pattern</u> of forest development is a consequence of (external) disturbance, induced or not by man, on a large or small spatial scale, occurring with variable frequency and intensity.

Interference and even synergism between both patterns is quite possible. They often occur simultaneously, One chain of events may facilitate processes belonging to the other pattern or increase their impact. The allogenic pattern is primordial in this respect. It is essential to the effect of silvicultural intervention, to be considered as a mild form of external disturbance, which endeavors to control internal stress. It is therefore necessary to evaluate all silvicultural activity in an ecological context, taking into account the intensity and frequency of local external disturbances of natural origin, which can further or obstruct the beneficial effects of any forest treatment.

1.2. The ecological approach

Adopting a broader definition, easily acceptable to forestry, van der Maarel (1978) understands degradation as damage done to an ecosystem. Each system performs a number of functions, valuable to human society. Their importance is variable. They interfere with each other. In this sense, damage can be equated with loss of functionality, van der Maarel expresses further the belief that most (not all ?) functions can attain a possible maximal value (to interpret as maximal level ?). Over-use, over-exploitation and the transgression of some outer limits may produce decline or complete exhaustion of one or more functions.

Holdgate (1978) holds much the same view. He considers a degraded or devastated ecosystem as one whose productivity or value to society is impaired. It has been modified in a most unwelcome way : Its value is seriously reduced and its restoration, if possible at all, requires considerable expenses.

Restoration, in his opinion, necessitates a double approach. From a conservational point of view, certain 'outer limits', which determine the integrity of a system, must be restored and sustained. The exploitational approach, on the other hand, requires to sustain a satisfying functional system or to restore it to the condition, where it can provide a desirable and, possibly, a maximal benefit.

The opinions of van der Maarel (1978) and Holdgate (1978) meet, to a certain extent, the classical concept of forestry on the importance of functionality as a parameter for the assessment of the forest condition. In forestry - as in ecology - it is wise to give a sustainable level of functionality precedence over a maximal level, which may be hypothetical and difficult to maintain. The problem, created by this line of thought in forestry as well as in ecology, resides in the variability of the relative importance of different (forest) functions in time and space.

Functions, related to site conditions, environmental requirements, biological features and sheer material production, can be clearly defined. It seems feasible to determine their attainable and sustainable maximal or optimal levels.

Other functions, especially those concerning the qualitative aspects of economic and social forest use, are highly variable from place to place, from one time period to another.

A third group of very important functions belongs to the future. They are mostly still unknown and extremely difficult to imagine. The fundaments for these future functions must, nevertheless, be laid down in our time. They impose the ethical obligation to bring and maintain the forest in such a state, where it is able to act and to continue acting as a functional reserve. The only possibility to create such a situation resides in the unconditional promotion of maximal forest stability, even if this requires actual restraint in the enjoyment of otherwise highly appreciated forest functions.

Sukopp (1978) opts for a different ecological approach toward ecosystem devastation where he accepts two types of degradation and characterizes them by their difference in impact.

He first of all considers retrogression, as formulated by Whittaker & Woodwell (1972). It is produced by chronic disturbances and stress, applied by man to natural communities, provoking changes that are the reverse of succession. This idea belongs to the field of phytosociology and is very dear to certain conservationists. Its real base is the acceptance of unidirectional evolution of the ' undisturbed' plant community toward a climax with maximal diversity and the highest degree of internal stability.

The second type of degradation corresponds to real loss of naturalness. Sukopp (1972) elaborated to this end an evaluation system, recognizing 6 states of decreasing naturalness or hemerobiotic grades, defined by the effects of human influence on ecosystems.

It is difficult to accept the approach by Sukopp (1978) as a device to measure degradation or breakdown of a forest ecosystem.The simple classification of the same kind, worked out by Leibundgut (1975) (Naturnaher Wald; Naturferner Wald; Naturfremder Wald; Kunstwald) is much more useful to this end.

It is evident, on the other hand, that regression can also have natural causes. It is further extremely difficult to deduce the real origin of a regression from the observed results if it was impossible to follow the complete chain of events from the beginning or even from an already advanced stage of succession. This is particularly true in the case of regressive evolution in the long-lived forest.

Additional skepticism about the system by Sukopp (1978) goes out from the constatation that at its core is a global assessment of all effects, known and unknown, due to voluntary or involuntary human influences on the ecosystem. The state of hemeroby is subsequently deduced arbitrarily from these effects on the habitat and its organisms. It is not quite clear how an assessment of this kind could be applied to the complex forest ecosystem, suffering manifold biotic and abiotic disturbances and influences with cumulative impact in time and space.

Quite different parameters for forest degradation are used by Godron (1968, 1975, 1978), going out from the particular situation in the Mediterranean Region of France, more specifically the incidence of destructive fires on the vegetation. The analysis of the consequences of forest fires incite him to formulate the hypothesis that the main difference between para-climax and eu-climax resides in the respective height of above ground vegetation and the vertical profile of biomass distribution. Natural selection is the force behind vertical differentiation in an undisturbed 'natural' forest. It causes the disappearance, at any moment, of weaker elements and promotes the dominance of trees with a well-developed uptake system. The graphic representation of vertical biomass distribution in a forest, not affected by fires, as conceived by Godron (1978), is comparable to the equilibrium curve for h-distribution in a forest, managed under the classical selection system (Plenterwald).

In the opinion of Godron (1978), reduced height growth and an outspoken tendency toward uniformity should be interpreted as indicators for relative degradation, due to insufficient water supply after external disturbance, especially if site and vegetation were affected by fire.

From a silvicultural point of view, it could be interesting and profitable to explore the possibilities of the use of modifications in vertical biomass distribution and vertical forest structuration as indicators for eventual forest degradation, related to water deficiency. Equally suggestive is the idea that uniformisation and, by extension, homogenization, whatever their origin, hint at marginality or, at the very least, at increased vulnerability of the forest.

Wein (1978), analyzing the ecological repercussions of forest fires, concludes that degradation is evident when after a fire, the ecosystem components do not recover to the expected degree in the course of the normal fire frequency period. He does, nevertheless, not equate species change with degradation as a matter of principle.

Such statements are controversial and equivocal. They fail to answer the fundamental question whether degradation must be regarded as a phenomenon, affecting the whole system as an entity, or is to be considered as the integration of unwelcome evolutions and changes, affecting its components.

In a more direct approach, Frederiksson (1978) presents abnormal nutrient loss as a main key to degradation of terrestrial ecosystems. Ulrich (1978) confirms this view. He specifies that losses of nitrogen and phosphorus are to be seen as critical steps in forest degradation.
Bradshaw, discussing these statements at the Reikjavik Conference, attributes primary importance to the study of soil conditions and the movements of nutrient reserves in the soil. Such a study helps to define the key stages in degradation and, hence, also in the restoration of degraded eocsystems (Holdgate & Woodwell, 1978).

The preference for the study of soil conditions over phytosociological analysis and the significance, attributed to the efficiency of water supply and related translocations of minerals in the soil, concord, in a broad sense, with the views of Bormann & Likens (1979) on the importance of internal organization and biotic regulation in the forest. They postulate both features as optimized during the steady-state phase of cyclical forest development : At that point the community exercises maximal control over water flow, the movement of minerals and the translocation of particulate matter; no important changes of biomass over time occur; annual ecosystem respiration approximately equals gross primary production (R=BPP).
An equivalent opinion, but based upon community development in a more phytosociological sense, is expressed by Werger & Westhoff (1985) in their definition of homeostasis as an optimal state of internal regulated regeneration of a living

ecosystem.

In both views, but especially following the line of thought chosen by Bormann & Likens, degradation can be defined as a definitive loss of biotic regulation beyond acceptable outer limits and whatever the cause. A spontaneous reversal of the situation and complete restoration of the original state are highly improbable or would require a long time. Technical intervention appears to be the only adequate solution to reverse the attained situation within a reasonable delay.

1.3. Evaluation

Contemporary silvicultural and ecological theory accept basically the dynamic character of the forest ecosystem. They also acknowledge the possibility of an optimal forest state, corresponding to the prevalence of (biological) production over losses and biomass destruction during the greater part of the normal life cycle.

Control over the hydrological situation in the forest is mainly attributed to the regulative effects of transpiration and water storage. Control by the living community over the movements of water, minerals and particulate matter results in control over erosion and energy output.

The acceptance of modifications in species composition, more specifically the reduction of the number of tree species as a distinctive feature of the optimized steady-state, rests on observation of cyclical forest development. This constatation does apparently not agree with the classical phytosociological concept of maximal species diversity as a parameter for community stability and as one of the essential characteristics of the climax. It becomes increasingly clear to the silviculturist that the reduction of tree species in the course of normal forest development is not to be accepted, unconditionally, as indicative for actual or even potential forest degradation. In some cases,
this phenomenon has quite the opposite significance (Van Miegroet, 1984).

The study of forest development, hence, of forest degradation must take the longevity of trees and the considerable life expectancy of most forests into account. To survive a forest must be able to absorb or gain control over different types of disturbance, occurring several times during the period dominant trees need to reach physical maturity.

Forestry would be well advised to consider losses of functionality,disturbed internal regulation and decreasing community control over water and nutrients as suitable parameters to evaluate occurrence and degree of forest degradation. Such an evaluation requires a specific approach to complement information, already obtained by traditional silvicultural analysis.

The assessment of functionality and its eventual decline poses no problem. Different fields of functionality enter into consideration (economic, ecological, social, biological, information, carrier, sanitary functions). They can be conventionally graded (non-existent, poor, medium, good, excellent). Integration of these gradings in a global index for functionality is possible.

For structural analysis existing methods, used by silviculturists (equilibrium curves; I.U.F.R.O.. Tree classification, etc.) are sufficiently adequate. Eventual adaptations to enlarge their scope could easily be made.

The evaluation of soil conditions and their modifications requires the organization of a specific research activity, including close cooperation with specialized pedology.

A certain difficulty could arise concerning the appreciation of changes in species composition. Misunderstandings are mainly caused in this field by doubtful generalizations of the significance, attributed to the reduction of the number of species as an indicator for unwelcome and regressive evolution.

Wein (1978) does not wish to equate species change with degradation.

Homogenization or reduction of variety in several directions (number of species, tree dimensions, tree age) must be seen, to a certain degree, as acceptable consequences of natural selection in the forest. It results in a continually decreasing number of dominant trees, requiring more individual space as they go on growing and developing (Van Miegroet, 1984). Species with a low life expectancy are the first to disappear. The relative dominance in numbers of species with a more considerable life expectancy, which quite often are also more tolerant, increases automatically in the course of this process.

Borman & Likens (1979) also consider a reduced number of species as typical for the steady-state, when the biocenosis has maximal control over site conditions.

If species content is to be used as a parameter for forest degradation, it is advisable to start with the study of the changing relationship between integrated species, functioning as fully established components of the (forest) ecosystem, and non-integrated species, depending on man for their perpetuation (Sukopp, 1978). The most indicative aspects of these relationships are the relative number of stems, the vertical distribution of species and the repartition of biomass over species and tree-classes.

Equally important and significative is the changing relationship between intolerant pioneers and more tolerant late-succession species. Shifting phenomena and the increasing relative importance of the tolerants indicate a reversal from an exploitative toward a more conservative natural strategy (Van Miegroet, 1984). The perpetuation, in sufficient numbers and in dominant position, of the tolerant tree species with a higher life expectancy is proof that a satisfying degree of forest stability has been attained. A reduction of diversity and a tendency toward homogenization accompany this stabilization process.

2. RELATIONAL ASPECTS OF DEGRADATION

2.1. Perturbation and disturbance

Disturbance and perturbation are often used as synonyms by some, but given a particular and distinctive content by others.

Louckx (1970, 1985) defends the idea that 'perturbation' applies to the whole system orientation. It concerns any change in a parameter that defines the system (Louckx, 1978, cit. by White & Picket, 1985). It is however extremely difficult to make the distinction between perturbation, as defined in the former sense, and the normal variance of the parameters of a system. This position is argumented by the fact that, in many cases, it is nearly impossible to obtain an unequivocal view on the 'normality' of the environmental settings of a given living system.

Subsequently, White & Picket (1985) hold the opinion, that perturbation must be considered as a departure from an explicitly defined normal state, behavior or trajectory of a system, but on condition that the observed cause of change is well known to be new to the system. They caution against deliberate use of the term 'perturbation', because it is difficult and unlikely to characterize in detail most natural systems.

Therefore, it is better to consider any relatively discrete event, that disrupts an ecosystem, a community, a population structure and changes resources, substrate availability or physical environment (White & Picket, 1985) as more meaningful from a practical point of view. A disruptive occurrence of this kind can be qualified as a 'disturbance'.

The term 'disturbance' contains two elements : It applies to a destructive event and it indicates environmental fluctuation (Neilson & Wullstein, 1983). To be applicable, this definition must be sufficiently related to acceptable community dimensions in time and space. To forest management 'disturbance' implies spatial dimensions of destruction, surpassing several times the actually attained height of the dominant trees. As to its time scale, a particular disturbance has to occur at least once within the average life span of the trees under consideration.

Quite often, it is nearly impossible to make the distinction between disturbance and quasi normal environmental change. Disturbances open up space and make some resources better available. They create opportunities for forest regeneration or recolonization of the site by fast-growing species, typical for the early phases of succession. Consequently, a disturbance can enhance species diversity, but it can also cause complete site denudation for a long time or provoke temporary or permanent dominance of less valuable species. By its fairly regular recurrence it may even become a constant site factor and a parameter for cyclical stability. This is the case of forests on steeper slopes, which are repeatedly destroyed by landslides with an interval shorter than the average life span of the tree species, that, in the absence of any disturbance, would normally dominate the attainable climax. Such occurrences provoke, in fact, that pioneers, in some kind of quasi cyclical evolution, replace more tolerant tree species with a higher life expectancy, that, otherwise, would have been the main source of forest regeneration.

The damage, done by any disturbance, is directly related to the magnitude of the destructive force, the characteristics of the exposed organisms and the substrate on which they live (Sousa,1985).

This combination of circumstances has to be taken into consideration by practical forestry. Sound forest management must, in due time and as soon as possible, take precautions to prevent disturbances or to minimize their impact.

By the creation of stabilized forest structures, promoting adequate mixtures of species, different in age, dimensions and functionality, the damage expectable from stormwind, snow pressure, avalanches, landslides and even floods, can be seriously reduced. This task is delicate on poor sites with low mineral resources and restricted water availability, not in the least while disturbances usually have there a more devastating impact as on better sites. Under all circumstances, whether for research or in planning technical intervention, it is essential to analyze the effect of disturbance at different trophic and biological levels of the forest ecosystem. It would be a grave error to restrict interest to the tree populations.

Even a superficial analysis of cause and effect will deliver ample proof that disturbances can profoundly modify the availability of water and nutrients, indispensable for plant growth. This alteration works in two opposite directions if considered on a broader time scale (Canham & Marks, 1985). Immediately after disturbance, a higher amount of radiation energy, water and mineral nutrients is at the disposal of remaining or newly established vegetation components. The main reasons for this phenomenon are the acute decrease in biomass on the affected site, the corresponding diminishment in uptake of water and minerals and the evident reduction of transpiration pro surface unit. Simultaneously, insolation increases manifestly and stimulates the decomposition of organic matter in the soil or deposited in considerable quantity on the soil surface, making still more nutrients available (Bormann & Likens, 1979) for plant growth and site resettlement. The vegetation takes immediate profit from the apparent improvement of growing conditions.

However, the advantages, thus gained, are short-lived as the increase in water and nutrients availability is clearly transient. Pretty soon after disturbance, the biomass starts to increase again, fairly quickly reversing the situation through the increase in uptake and transpiration. This quick reversal is typical for the better sites, in the case of rapid recolonization by expansionist pioneers or when the seed reserve in the soil was well furnished. Its effects are otherwise scaled up by the evident disruption of nutrient cycling (Christensen, 1977), physical degradation of the site (Nye & Greenland, 1964) and loss of water by increased evaporation following denudation. Both chains of events result in a drop in the amount of available water and minerals. They exerce a negative influence on plant growth, putting an end to the short period of initial improvement. They also tend to accelerate further site deterioration and erosion, both on the surface and underground.

One of the most important characteristics of any disturbance is its direct connection with outside driving forces, causing important change within the forest community. Although the working external influences are easy to recognize (stormwind, excessive snowfall, fire, landslides, floods etc.) and their effects are well known, it can, nevertheless, be difficult to make an unequivocal distinction between endogenous en exogenous causes of change. Some forests are more prone to disturbance than others because of their structure, composition, species content, use or type of management. The developmental state of a forest can enhance or diminish the likelihood of disruption because of temporary increase or decrease of vulnerability toward specific devastating outside forces. In older forests it may become extremely delicate to make out whether the disappearance of some dominant trees is the consequence of natural senescence, accelerated eventually by external influences, or exclusively due to exogenous factors.

Most disturbances are a nuisance, not only from a silvicultural, but also from an ecological point of view. They disrupt community development and evolution. It is quite evident that disturbances do not always act as resetters of succession in the forest ecosystem. Once the dominant trees and part of the lower stories are accidentally removed, there is no guarantee that the physical and biotic parameter of the site will return to the previous state by pure autogenesis.

It is equally important to keep in mind that recurrent disturbances are a mean feature of most long-lived forests, absolutely necessitating thorough analysis of the disturbance-regime. It co-determines, as a matter of fact, the interaction between species and nutrient cycles in the forest. By their scale, disturbances influence trophic levels, determine population stability and eventual co-existence between organisms with varying characteristics and tree species with different light (life) requirements (cfr. Armstrong, 1976).

Control over the impact of disturbances affecting the forest is to be gained through measures that permeate equilibrated forest structures, promoting diversity (species, age, tree dimensions), stratification and optimized horizontal and vertical occupation of space. Due attention should be given to the development of a multitude of trophic chains as a means to create sustained forest stability.

2.2. Stability

An undisputable diagnosis of forest degradation is difficult to make, as no unequivocal definition of its nature, suitable to all circumstances, seems to exist.

If degradation is regarded as the failure of spontaneous restoration of a disrupted forest state to the original or natural situation within a reasonable period of time, it is quite legitimate to ask questions about the point of departure.

Over a long time, nearly all vegetation communities were profoundly modified by direct or indirect human influence. It is equally unclear what must be understood by ' a reasonable period of time ' for spontaneous rehabilitation, considering the longevity of trees and forests or, even more important, the acceleration and intensification of human impact on the forest in our time.

The real nature of the eu-climax is nearly never known completely or beyond serious doubt. Man can induce negative as well as positive site changes (Godron, 1978). Consequently, it seems quite unsuitable to assess the degree of degradation of a forest ecosystem by comparing an actual state of depravation with an ideal, but theoretical climax.

Human influences belong to the main causes of global forest modification. They often bring the forest in a condition, where it suffers increasingly from internal stress or becomes more vulnerable to disruption by other outside agents. Ever since agriculture developed, especially since the neolithicum, when man, for the first time in history, gained some control over biochemical processes, the environment began to change under the pressure of human presence. Even before that crucial time, already during the mesolithicum, considerable human influence was exerted on a large scale by the use of fire and/or the manipulation of populations of herbivores (Dimbleby, 1978; Delvaux, 1987).

Ample proof exists (pollen analysis) of successive clearance and regrowth (Turner, 1965) or subsequent return of the forest (Smith, 1975). In some (exceptional) cases, the forest regained its original dominance or the specific composition, upset by human intervention, restored itself (Dimbleby, 1962). Such a complete recovery, however, occurs rarely. In most instances, succession after clearance leads to a weaker representation of the forest ecosystem or to its definitive disappearance. Continuated agricultural land use or profound deterioration of the environment (Turner, 1965) are responsible for this evolution.

Dimbleby (cit. Holdgate & Woodman, 1978) confirms the complexity of the situation when asking what a successful restoration is and to what the system is to be restored, to something like its previous configuration or to something new. He further expresses the opinion that, nearly always, a new situations is reached, where it has become impossible to recover preceding situations, provided the previous state should be known beyond doubt.

For this reason, Polumin (cit. Holdgate & Woodman, 1978) is quite right asking if it would not help if discrimination between natural and modified situations was stopped since man is so universally dominant. He thinks it more creative to aim at moving systems to the conditions, where they are most desirable. Such a statement implies the acceptance of functionality as a parameter by which to evaluate the actual state of an ecosystem, including its eventual degradation or rehabilitation. It reduces the problem to a question of control or loss of control over the factors, which make a forest more or less useful. It can also help to determine the qualitative and quantitative aspects of a desirable and sustainable level of forest stability.

Plausible interpretation of these opinions may lead to an alternative perception of forest degradation, going out from the concept of stability, linked to sustained functionality. It accepts the reality of the actual forest situation and regards the forest ecosystem as a complex entity. It concentrates attention on site conditions in their relationship to the whole biocenosis and, more particularly, to the tree populations.

Disturbances, natural or induced by man, not in the least through forest use, planned management and silvicultural treatment, provoke minor or major changes in forest composition, texture and structure. They occur frequently, act as agents of selection and become part of continual forest development. Eventually, they help to increase forest resistance against internal stress or exogenous agents of destruction.

The changes they provoke are not always reversible. Neither must they necessarily have an automatic decrease of homeostasis as a direct consequence. The forest is a highly dynamic system. It has to absorb the many stresses, caused by its own longevity and the considerable life expectancy of its dominant components. Continual change, on a variable scale of time and space, is a prevailing feature of the living forest. Therefore, the term 'stability' must be used with great circumspection as a parameter for the incidence or absence of degradation of the forest ecosystem.

'Stability' is a rather composite concept. It contains a purely mechanistic element, but also applies to the biological and ecological aspects of a living community. In its application to a forest situation, it can be approached from different sides. It is useful to evaluate the condition of natural as well as of modified or artificial forest ecosystems.

Under 'normal' conditions of mild allogenic disturbance, either natural or induced by man, a forest ecosystem can remain or appear to remain unchanged over a vast area and over a long period of time. In this case autogenic disturbances, caused by individual tree growth, the development of populations and the relief of internal stress, are well absorbed by the system. The impression of immutability, however, may be deceptive. Changes always occur, but they may be restricted in space and have only temporary importance. This type of situation is fairly typical for some natural, unused and unmanaged forests. It is also to be found in forests under intensive, but conservative management or when silvicultural treatment anticipates spontaneous forest community development and seems able to exerce sufficient control over the forces behind permanent redistribution of space and access to the sources of energy (Plenterung. Selection system).

In both cases, in the untouched natural forest as well as in the well-protected forest under management, a state of constancy or structural and more or less static stability arises, with fairly constant forest functionality as a direct consequence.

However, under actual circumstances, most natural and semi-natural, modified and outright artificial, but well-managed forest ecosystems have increasingly to endure severe external pressure, which provokes modifications in species content, structural decline and abasement of the biomass level. Because of the synergism between prevailing exogenous disturbances, occurring repeatedly and often periodically, and the phenomena of internal stress, due to the dynamics of individual tree growth and community development, a considerable release of space can take place, resulting in regeneration bursts (Huse, 1963; Louckx, 1970; Connell & Slatyer, 1973), which are less evident in artificial or man-made forests.

If such disturbances are persistent, occur frequently and show an irregular pattern, no stable situation can develop and a state of permanent unrest is generated. Most often, degradation is unavoidable because of physical site deterioration and gradual impoverishment of local regeneration sources.

If, on the other hand, important release phenomena are less frequent or coincide, up to a certain degree, with the arrival at maturity of the greater part of the dominant trees, some kind of cyclical stability can come about. An absolute condition for this type of pseudo-synchronized development is the availability, at the right moment, of good regeneration sources, able to warrant reoccupation of released space within a reasonable period of time. If this is not the case or if no technical interventions to prevent degradation are undertaken, retarded or failing restoration can influence negatively both site and forest functionality.

Although important from a silvicultural point of view, it is, ecologically speaking, fairly irrelevant which type of stability - constancy or cyclical stability - is preferable. Much depends upon local conditions. Both types of stability can correspond to an acceptable situation if, because of an excellent relationship between biocenosis and site, quick restoration of internal regulation is guaranteed. Their perpetuation is closely linked to the degree of destabilisation, produced by disturbance in relation to site and environmental change. Extremely important are the tree species, available for regeneration.

Constancy and structural stability correspond to rather mild, but frequent autogenic disturbances with limited spatial impact. They are observed in mixed forests with predominantly tolerant tree species, characteristic for the later phases of natural forest succession. Their maintenance can be assured under limited allogenic pressure, inclusive silvicultural intervention, if natural community development is basic to forest management.

This type of stability and, consequently, of corresponding silvicultural intervention is characterized by the dominance of late-succession species, approximative constancy of biomass and its outspoken vertical distribution.A conservative or interventional strategy prevails. Stability in time has or is given precedence over stability in space (Van Miegroet, 1980,1984).

Cyclical stability is more typical for forests, where large-scale disturbances, natural or directly and indirectly man-induced, occur frequently and are combined with gregarious development of populations and sub-populations of less tolerant tree species. It reflects a natural strategy to exploit all opportunities for quick resettlement of larger space units with fast growing pioneers, often adapted to local conditions and promoted by forest management. Recolonization in this case shows a pattern of horizontal distribution of biomass and age-classes. As such, the maintenance of cyclical stability can pose serious problems to forest management. In an ideal situation, it concurs, under natural or managerial circumstances, with an equilibrated distribution of all stages of forest development, each phase occupying a total area, directly correlated with its average duration.

The subdivision of the total area, covered by each developmental phase, into an increasing number of ever smaller space sub-units, determines the gradual effacement of the fundamental differences between structural and cyclical stability. Such a progressing subdivision of space has far reaching consequences for silvicultural treatment and forest management. It corresponds, in fact, with the gradual effacement of the fundamental differences between group regeneration systems (Femelschlag) and the selection forest system (Plenterung), as well as with the transition of an exploitive toward a more conservative strategy.

This opinion can be justified by the analysis of both systems. Structural and cyclical stability can both serve as basic models in forest management and silvicultural manipulation of the forest.

Nearly continual regeneration, outspoken vertical differentiation and approximately constant biomass are typical for the classical selection forest of the european pre-alpine regions. Here most changes are introduced by local relief of internal stress. This relief can occur spontaneously or be caused by human intervention through forest use or silvicultural treatment.

Cyclical stability is more in evidence or aimed at in silvicultural management systems, that go out from group regeneration. Exogenous disturbance, particularly through ordained forest management, prevails over large space areas, more or less regularly dispersed.

A link exists between stability types and geographical or topographical conditions Cyclical forest stability and group regeneration systems are predominant on flatlands.

Human occupation of the corresponding regions started early and forest clearance to obtain space for agriculture and grazing was and is relatively easy. It occurred already in neolithic times (Dimbleby, 1962) in Europe, creating excellent opportunities for subsequent establishment and later dominance of pioneers and more light demanding tree species.

At higher elevations, forest clearance was not so attractive or usual until recently. Natural selection under extreme environmental conditions, nearing the upper limits of forest dispersal, resulted in a natural conservative strategy, which promoted and perpetuated the dominance of tolerant and resistant tree species. When man started living in these mountainous regions, he soon realized the importance of forest presence to his own survival. Stabilization of the environment and regular delivery of much needed materials, to be produced by the forest, became the principal aim of eventual forest management, even in its most primitive form. Man, quite logically, opted for a conserving type of forest use. By empirical observation of the natural course of spontaneous forest development, he discovered the fundamentals of responsible forest management

Constancy and cyclical forest stability can become seriously endangered by severe and repeated exogenous disturbances, especially by those of human origin.

If the forest is able to absorb the shock of destabilisation and possesses a sufficient degree of resilience, its reaction, even to fairly heavy disturbances, can be limited to minor change. If regeneration conditions are not deeply disturbed, restoration of the forest to its previous or an equivalent state can follow within a relatively short time.

If, however, a forest is not resistant enough and if the outer limits of elasticity are transgressed, the damage can be serious. Degradation follows inevitably if the situation is not quickly reversed by planned human intervention. Technical measures are advisable as soon as there is sufficient evidence that natural reversal will take a long time, has restricted chances to occur or will lead to a secondary forest with less biological and ecological content.

Forest management and forest use by man are to be considered as allogenic (=exogenous) disturbances. They can surely cause forest degradation if a certain amount of restraint is not observed. This must be ample reason for forest management to choose the promotion and unconditional maintenance of forest stability as its principal objective. The limits of resistance and elasticity of any forest stand under treatment are to be studied in order to be able to fix the limits of interventional action. Such an exploration permits to assess the possibilities and consequences of positive reaction to intervention and to define the nature of the most advisable silvicultural treatment.

Theoretical and practical analysis of forest stability, degradation and restoration is fundamental to the practice of silviculture.

The basic forms of disturbance (autogenic and allogenic; restricted or extended in space) correspond to the basic models of classical forest management.

An undeniable relation exists between the disturbance type and the attainable stability type. Consequently, a parallel relation exists between a chosen type of management and the kind of stability it can aim at.

Cyclical stability relates to allogenic disturbance to a remarkable degree. It generates forest renewal in groups and is basic to all systems, characterized by this type of forest regeneration. In the group regeneration systems, the limits of resilience of the forest and, consequently, of the outer limits of intervention are defined by the attainable type of cyclical stability in combination with the degree of elasticity of the complete forest ecosystem.

Constancy or structural stability, on the other hand, is more linked with autogenic disturbance, restricted in space and predominantly caused by the relief of internal stress. The forest does not suffer severely if it is in good health and sufficiently resistant. This type of stability corresponds to a management system, based on individual tree exploitability and spatial restriction of each separate regeneration unit.

2.3. Vulnerability

The vulnerability of an ecosystem is to Holdgate (1985) the expression of its tendency toward loss of productivity under external stress. In this sense 'productivity' can be replaced by 'functionality' or must be understood as the intensity of the energy flux, passing through an ecosystem.

The vulnerability for degradation of a forested ecosystem depends entirely upon its susceptibility to exogenous disturbance, provoking change and quantitative and/or qualitative loss of functionality. Assessing vulnerability, normal and site-linked patterns of disturbance, characterized by their type, frequency and intensity, must be taken into consideration.

As a relation exists between degradation and the biotic and abiotic components of an ecosystem, its physical features and occurring physical, chemical, biological, physiological and biochemical processes, so can susceptibility toward external stress be manifest in one or more of these fields, either separately or simultaneously.

It is important and even necessary to evaluate eventual interaction between components, processes and components-processes. Separate susceptibility to disturbance can, in the end, provoke undesirable modification of the whole system and of the components and processes it contains, engendering its ultimate degradation.

Such an approach rejects vulnerability as the inverse of resistance. This must, however, not prevent to ask the question what makes a system resistant to what kind of challenge (Régier cit. Holdgate & Woodman, 1878) as an inverse method to study vulnerability.

Degradation does not automatically follow disturbance. Its occurrence, as a matter of fact, depends upon a number of elements, some known and others still unknown.

The most important are : the type, intensity and frequency of disturbance; the basic characteristics of the endangered ecosystem i.c. the forest; the developmental stage, attained at the moment the disturbance takes effect; the location, together with its geographic, geomorphological and climatic particularities; the synergetic phenomena or interactions between ecosystem components, as well as between the composing factors of a given disturbance.

In a more practical approach, the specific conditions of stress, originating in the use and the management of the forest, deserve special attention. They can exert a great amount of pressure on the forest, thus enhancing considerably its susceptibility to additional external influences.

Some of these stress-factors have their origin in prevailing orientations of forest management :

- Forest homogeneisation by wilful reduction of the number of tree species for technical, economic or financial reasons.
- Clearcutting practice over relatively vast areas with loss of energy, water and mineral reserves as a direct consequence.
- Structural uniformisation by the acceptance of a management system, based on 'normal' age-class distribution.
- Orientation of management toward arboriculture and tree farming with poor links to real silviculture.
- Maintenance of a state of excessive stand density, aggravating considerably the danger of abiotic perturbation.
- Relative ecological and biological impoverishment of the forest ecosystem, as indicated by the low amount of standing necromass.
- Periodical disturbance of biological soil activity and soil stability, due to silvicultural activity and
  forest exploitation, especially logging.

A still greater negative influence goes out from technological stress factors. They make, in combination with the kind of stress, generated by silvicultural intervention and traditional forest management, the forest highly susceptible to even the slightest of external disturbances :

- Infrastructural development, particularly road construction in or in the immediate neighborhood of the forest.

- The growing tendency toward 'chemicalisation' of intervention by the use of excessive quantities of mineral fertilizers and the organization of biological control through systematic application of biocides.
- Mechanization of silvicultural interventions, resulting in the creation of

unrest and the introduction of unusual materials into the forest.

- Use of heavy machinery for tree harvesting, which aggravates the already existing situation of unrest, is a direct cause of disturbance, producing soil compaction with dire physical, biological and ecological repercussions.

The increase of stress upon the forest seems inevitable under the actual conditions of demographic evolution, industrialization, growing differentiation of forest use and worldwide ecological deterioration. It can and must be kept within acceptable limits to warrant forest survival. A first step in the good direction consists in the treatment of the forest not only as an ecosystem, but as a very vulnerable one. A sound ecological background is to be given to silvicultural treatment and forest management.

2.3.1. The disturbance type

White & Picket (1985) consider as the main descriptors of disturbance its distribution, frequency, return interval, predictability, area or size, magnitude (intensity and severity) and synergism.

More suitable for the analysis of the influence of disturbance on the forest in particular are, however, the descriptors, proposed by Runkle (1985) :

Average distribution rate.
Distribution of disturbance in space :
Relative to the environment.
Relative to the size of the disturbed area.
Relative to (tree) species composition (of the forest).
Distribution of disturbance in time.
Severity of disturbance.
Rate of recovery.

It makes sense to complete both systems of description by the assessment of the type of damage and the evaluation of possible or predictable reactions of the community. It is also advisable to differentiate between spontaneous recovery and the potential for induced rehabilitation, between the actual state of recovery and an attainable finality.

To this end it is useful to adopt the interpretations by Bormann & Likens (1979) and Oliver (1981), who distinguish three fundamental types of disturbance, based on the amount and the kind of damage they cause :

a. Mild disturbance, consisting in the elimination of canopy trees, to which the forest community reacts by directly filling the released space by saplings, already present before the disturbance occurred (= suppressed saplings strategy).

b. Severe disturbance also eliminating suppressed saplings, but letting the soil intact, to which the community reacts by the emergence of species, present in the seed pool (Marks, 1974) (=seed pool strategy).

c. Severe disturbance over a larger area eliminating canopy trees, suppressed saplings and seed pool, accompanied by profound modification of soil conditions, which requires a protracted recovery time (=recovery strategy), but, in most cases, leads to real degradation.

In last analysis remains to be said that the vulnerability of an ecosystem depends, for a great deal, upon the vulnerability of its components, but this approach complicates seriously the solution of the problem. On the suborganismal level, disturbance mainly has physiological effects (Sousa, 1985); on the organismal level changes in behavior are to be expected (Wiens, 1985); on the ecosystem level nutrient availability will define whether or not real degradation will occur (Vitousek, 1985).

The interference between these reactions on different levels is still not well known. The intensity and extension of separate phenomena can, nevertheless, be used to study the vulnerability of an ecosystem, on the absolute condition that their direct effects are accurately and correctly assessed.

In the same line of thought, it is also essential to analyze the synergism between disturbing forces.

The study of site conditions and state of the forest (structure; texture; species content; biomass distribution; growth relationships) in direct relation to human behavior under well-defined climatic circumstances can further give ample warning on the potentiality of forest degradation.

2.3.2. The forest type

Homogeneous, even-aged and structurally uniform forests, especially the man-made forests of this type, are generally considered as most susceptible to the impact of exogenous disturbance and, consequently, to degradation. This opinion is based on the fact that such forests either grown on extreme sites or, if established on better sites, do not sufficiently translate site variability into structural variation and species content to the extent that real homeostasis is not realized over a larger area

If in the homogeneous man-made forest, which is already more vulnerable by its origin, the chosen species are, in turn, particularly susceptible to a specific type of frequently recurring disturbance, ultimate degradation of this forest type is nearly inevitable.

It is a curious coincidence that such degradation can be followed by partial restoration of the original or quasi-natural tree species composition if some seed-bearers remain in the neighborhood or the original seed pool is not entirely destroyed.

From such a spontaneous rehabilitation after degradation a forest type can arise, that is more valuable, at least from an ecological or biological point of view.

The choice of species in afforestations or in case of directed natural regeneration of an existing forest is equally important. Trees with a superficial root system, such as spruce and poplar, suffer most from all kinds of negative exterior influences.

The case of Norway spruce (Picea abies (L.) Karst.) demonstrates the linkage between biotic and abiotic factors in provoking fatal consequences of disturbance. Bazzigher (1969) found out that a previous attack by Fomes annosus Fries. is an important cause for the extension of storm damage in homogeneous spruce stands. Otherwise, spruce is not able to build up an effective defence against Fomes. This tree species is, furthermore, easily attacked in overdense middle-aged stands by Ips typographicus L, which, in turn, acts as a carrier for Fomes annosus Fries.

Older stands are more susceptible to storm damage because of loosened anchorage in the soil, due to chronic deperishment of roots, reduced vitality, decrease of physical resistance and sub-optimal sanitary conditions. For nearly the same reasons, sub-dominant trees are among the first to be thrown by stormwinds in homogeneous softwood stands. The remaining dominants will, eventually, be damaged or thrown in the course of a second pass if not enough time for recuperation was available and till then suppressed saplings and undergrowth were not given the opportunity to fill the gaps and to play a role in the building-up of new tree cells.

The main reason for the higher vulnerability of homogeneous forests for stormwinds is the close relation between community stability and individual tree stability. In this type of forest, all trees possess approximately the same degree of resistance against or, inversely, susceptibility for stormwinds. The cell structure, which normally enhances mechanical stability, is less pronounced. Once the most exposed and weakest components are thrown, the complete forest stand is in danger of complete collapse as mutual support is insufficient and the degree of external stress nearly the same for all trees, remaining in a stand, which is still more homogenized by the first attacks.

It would, however, be erroneous to consider mixture of species in itself as an universally working agent against stormwinds. Mixture stands, in fact, as a symbol for a specific vision on forest management, which prefers longer rotations, promotes natural regeneration in groups of autochtonous tree species as part of a well-ordained system of selection and gives great importance to intensive silvicultural treatment with its primary aim to adequately isolate the potential elite-trees in due time. Suchlike system of coordinated intervention promotes individual tree stability, whatever the species, and, consequently, collective community stability, not in the least by allowing the emergence of suppressed and sub-dominant trees, which are then able to perform a supportive role in the stability cells they form with the dominants and predominants.

For analogous reasons, storm damage is generally more important when and where clearcutting-systems are adopted. This can be partially explained by the consequences of acute site-denudation. Not less important, however, is the fact that clearcutting is closely linked with forest homogeneisation, shorter rotations and periodic total exposure of the site to direct external influences, which, under no circumstances, can be beneficent to soil conditions and their stabilization. Clearcutting leads to an outspoken preference for fast growing softwoods in homogeneous stands, inevitably shortening the periodicity of final exploitation. Less interest goes out to intensive forest treatment. One-sided orientation of forest management toward financial profit leads to late, less frequent and rather weak thinnings and all action is concentrated on the final crop.

It stands to reason that human actions modify biological and physical components of the environment, thus altering the nature and rate of their interactions (Holdgate, 1978). These modifications are basic to correct interpretation of the consequences of silvicultural intervention. They explain why forest treatment, particularly the adopted thinning regime, greatly influences the vulnerability of the forest stands for stormwinds.

A high degree of overdensity in younger stands due to neglected thinning (Bosse, 1973; Hase, 1976; Prosinagg, 1978) or thinnings made too late (Bazzigher, 1969; Hase, 1976) or brusque modification of stand density by heavy, but retarded thinnings (Bazzigher.1969; Zupanic 1969; Faber, 1975; Robert, 1976; Prosinagg, 1978) can make the forest highly sensible to wind damage. Early, moderate and timely thinning is considered beneficent to structural stabilization of a forest under management (Horndasch, 1971; Touliatos, 1971; Labanauskas, 1973; Sissingh, 1975; Faber, 1975). It is further recognized by Horndasch (1971) that the ultimate forest structuration and stability are determined by early development and human intervention during the juvenile developmentary stages. Intensive silvicultural treatment, culminating in timely executed stronger thinnings, is preconized by Zupanic(1969), Faber(1975), Sissingh (1975), Richter (1975) and others for its positive effects on tree morphology (more important stem diameter; crown covering 1/2 to 2/3 of total tree length; better root system), which promotes individual mechanical tree stability and, subsequently, forest stability and community stability. Faber (1975) even uses the h/d-ratio to evaluate or predict the potential threat of storm damage : A situation is considered dangerous when the h/d-ratio rises to between 60 and 70 and critical as soon as it attains 70 to 80.

Concerning the catastrophic snow damage in the forests of the Salzburger region in 1979, Pollanschütz (1980) draws analogous conclusions. Unthinned stands suffered less than stands thinned too late, but damage was minimal where stronger thinnings were executed in time. The h/d-ratio for elite trees should be kept below 70-80; catastrophic consequences must be expected when it reaches 100.

The susceptibility of a forest to excessive snowfall is directly related to its potential for snow interception. Therefore softwoods have more to suffer than hardwoods. Homogeneous stands of Norway spruce with normal density can intercept 42 to 62 % of actual snowfall (Watschinger, 1977). Younger stands suffer mostly under snow pressure; in middle-aged stands breaking of crown and stem are more to fear; older stands nearly never show substantial snow damage.

Köhler (1973) found a correlation between the intensity of snow damage and the spatial extension of even-aged younger stands. Köhl (1980) confirmed these observations, adding that the better resistance of the classical selection forest (Plenterwald) is to be explained by its outspoken vertical differentiation and the pattern of horizontal distribution of trees, with enough space provided for optimal development of the dominant trees.

Donaubauer (1980) also condems artificial forest homogeneity. He is convinced that the catastrophic increase in snow damage in Austria is due, to a certain extent, to systematic favorisation of Norway spruce and modification of the ratio Norway spruce/Silver fir from 1:1 in 1873 to 3:1 and even 4:1 a century later. Homogenization itself has a global influence on deteriorating forest stability. Donaubauer (1980) observes that it favors the spreading of cryptogamic diseases and furthers attacks by Fomes annosus Fries., resulting in tree losses, decreasing forest vitality and ultimate community degradation.

Homogenized softwood forests, especially if even-aged and a product of structural uniformisation, are vulnerable under many other aspects : Forest fires, air pollution, forest exploitation without ecological precaution are much to fear. Their impact grows with the spatial extension of these endangered forests, which, in the end, become a serious liability on a larger scale.

Evaluating position and principal ecological characteristics of man-made and profoundly modified forests and recognizing their inherent weaknesses, an idealized forest types comes easily to mind as the result of inverted reasoning. It has a complex pattern of mixture of species, tree forms and populations, growing in an intricate configuration of interdependence and well-developed vertical and horizontal structuration.

Such an idealized image corresponds, at least in the opinion of many people, with the state of the tropical rain forest in optimal condition. It is often believed to be invulnerable to degradation as long as human interference with its growth and development does not exist or remains restricted.

This forest type is, in fact, rarely subject to exogenous disturbances on a larger spatial scale and causing its ultimate disappearance, exception made for cataclysmic and nearly unpredictable events.

Disturbance is, nevertheless, not absent in the tropical rain forest, but it mainly creates small and quickly regenerated patches, involving the fall of only one or two trees (Hartshorn, 1978, 1980; Brokaw,1982). Its pronounced differentiation and extremely rich species content explain fully the absence of gregarious reaction and the higher degree of collective resistance against all kinds of biotic and abiotic influence from the outside.

However, contrary to the forests of the temperate and northern zones, the tropical rain forest is highly susceptible to logging and farming. Both activities remove the seed sources (Gomez-Pompa, 1972). They profoundly alter the delicate soil structure under extreme climatic conditions, so that irreversible soil degradation and subsequent forest community degradation often occur. Whitmore (1975) and Knight (1975) believe that, in such cases, several centuries would be required to reestablish the original composition and structure of the forest. Complete rehabilitation is not impossible, but highly improbable.

A superficial comparison of the man-managed forest of the temperate zone with its theoretical opposite, the tropical rain forest, can provide valuable information on the significance of species content and forest structuration, but it can not cover all situations. Therefore it should be done with great circumspection and avoid exaggerations or too optimistic generalizations. It includes, in fact, the danger of a distorted view on the fundamental processes of forest development and the way resistance against exogenous pressure is built up.

It otherwise remains a fact, that the relatively open and homogeneous forests of the boreal and alpine zones, although uniform over lager areas, show a simple structural pattern and grow slowly, but are, nevertheless, rather resistant against disturbance. Growing and developing under extreme environmental conditions, they are the evident product of site-linked natural selection. Regularly recurring minor disturbances of a specific kind determine their structuration. They seem only vulnerable to catastrophic perturbations, such as those caused by climatic change, landslides, lawines, vulcanism and floods. Contrary to the reaction of the tropical rain forest, they show a high degree of resilience after disturbance by human action (Denslow, 1985).

The relative superiority of mixed over homogeneous forests, as far as their resistance to degradation is concerned in regions where several tree species can persist and reach normal dimensions, is probably due to the fact that they contain a fair amount of light-demanding and opportunistic species or even pioneers, whereas the homogeneous forest is often characterized by the dominance of more tolerant or late-succession species. Heliophilous tree species have mostly a shorter life span and are, as such, less frequently exposed to catastrophic events. They grow fast and reproduce early, which is a favorable feature on sites with a high disturbance rate (Grime, 1979). They are often the selection product of a regime of mild, but frequently recurring disturbances on better sites.

The unequal specific resistance of tree species and populations to different types of disturbance may be another reason for the lower degree of vulnerability of the mixed forest and its greater resilience.

2.3.3. The developmental stage

The phenomena of growth, death and replacement ensure that biological systems are fundamentally dynamic (White & Picket, 1985).

The forest is a long-lived biological system. Its dynamics are determined by permanent redistribution of space and access to energy between its components. The principal force behind its cyclical development are individual tree growth and external disturbance on a variable space-scale with a mild, disastrous or catastrophic impact (Harper, 1977).

The internal stress between trees and clusters of trees, caused by growth, works in two directions : It can pave the way for destructive external influences if it provokes a general decrease in vitality; it can also enhance global vitality of the system if it provides sufficient space for optimal development of the dominant or most vital trees.

As long as the impact of allogenic or autogenic disturbance has no far-reaching negative effects on sub-populations of dominant and co-dominant trees, no real danger for forest degradation exists.

If the impact is spatially limited and only releases the space, formerly occupied by one or a small number of dominants, the gap, thus created, is quickly filled by ingrowth or emergence of till that moment suppressed understory elements.

Only if the impact of disturbance is severe and destroys total forest biomass or the greater part of it over a large area, real degradation can occur because site conditions are changed, the waterflow affected and the movement of soil minerals influenced.

Potential cyclical evolution of most forests taken for granted, the question remains whether the average forest is equally susceptible to allogenic disturbance at all stages of its development or are there developmental phases with minimal or maximal resistance to external pressure.

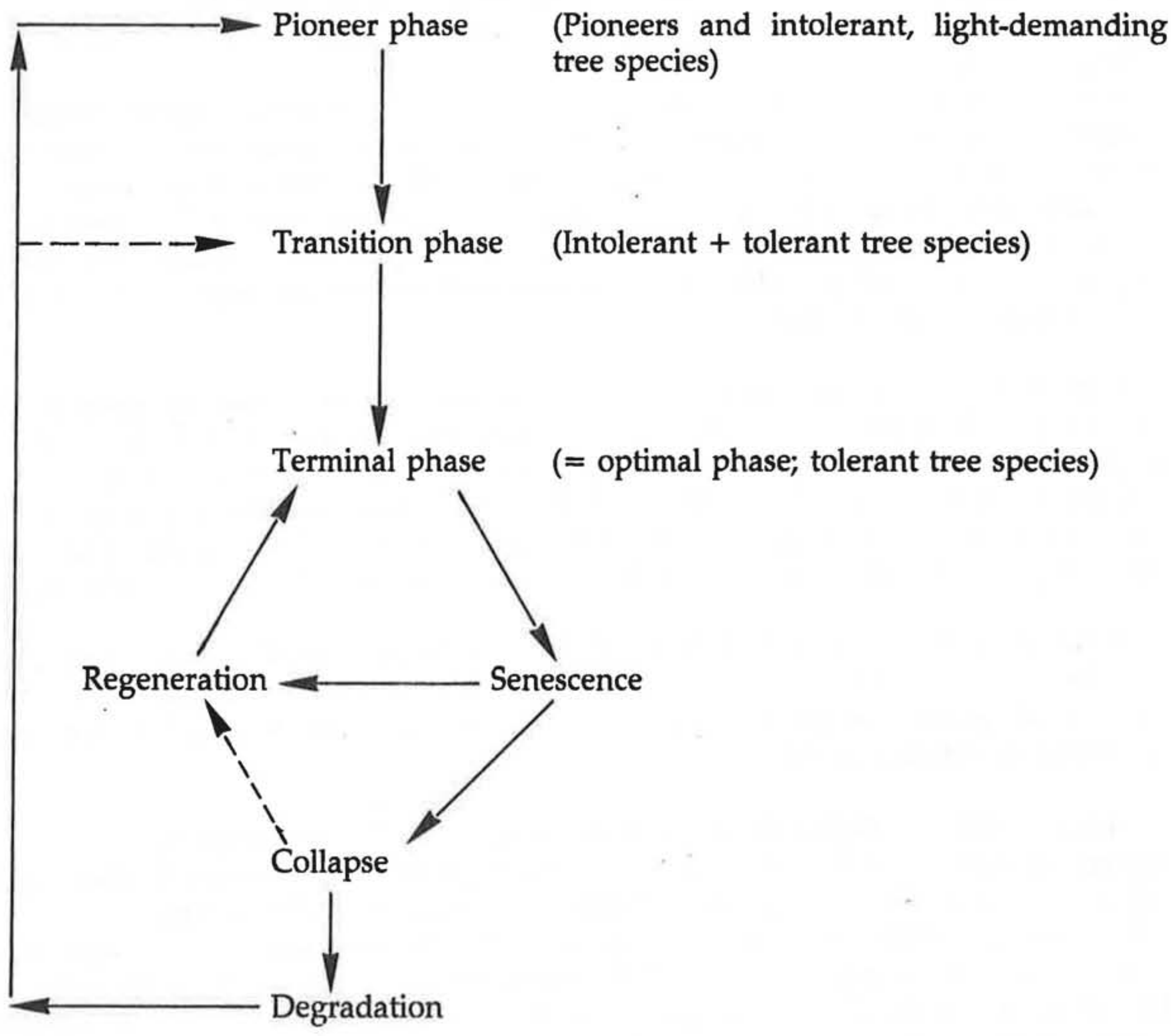
In the model, developed by Leibundgut (1977) (Tabel 1) the danger for degradation is potentially maximal in the terminal phase of forest stand development, depending upon the scale of time and space, on which mortality occurs.

If mortality remains restricted to the normal effect of senescence of dominant trees having reached the expected end of their physical lives and if mortality is not a gregarious phenomenon, little gaps are created to be filled easily by the combined actions of ingrowth and emergence with participation of dominants, co-dominants and understory elements.

Whenever the gaps are greater and the possibilities for ingrowth and emergence are poor or non-existent, seedlings may establish in the absence of repeated allogenic disturbance if enough seed is provided by dominant trees, remaining in the immediate neighborhood, or from seed storage in the soil.

In both cases, a situation of continual, but dispersed forest regeneration arises, eventually covering a time period corresponding to the average life expectancy of the dominant trees of to an important part of it. Such processes consolidate the position of the more tolerant late-succession species, which, normally, have a longer life span than the less tolerant tree species, belonging, to the early phases of forest succession.

Tabel 1 : Model of Leibundgut (1977)



In this way, unrest is always present in the forest ecosystem, but it is spatially restricted, thus excluding temporary global unrest. A mosaic of patches emerges where this sub-cycle 'optimal phase - senescence - regeneration - optimal phase ' remains closed. It is repeated as long as no serious allogenous disturbances occur. The relief of internal stress is the dominating force behind this type of cyclical forest development, either spontaneous or induced by management as in the case of the classical selection forest system (Plenterwaldbetrieb).

However, the fact remains that the susceptibility of trees for disturbance increases with growing age, so as to make the distinction between allogenic and autogenic disturbance less meaningful (Runkle, 1985). Therefore, if mortality occurs in greater clusters, even a mild exogenous disturbance can suffice to accelerate the process of deperishment : Local collapse of the forest may take place.

Localized collapse can result in forest regeneration and restoration of the optimal phase with dominance of the more tolerant species, whenever a sufficient number of suppressed saplings is available to take over and/or a good seed reserve still exists, allowing the establishment of new seedlings. This type of cycling is used or replicated by the forest management system, based on group regeneration (Femelschalgbetrieb). In both instances, spontaneous or induced development, the relative participation of tolerant and less tolerant tree species is determined by the spatial extension of the individual cleared area : reduction works in favor of tolerant species; extension works in favor of the light-demanding tree species.

A dangerous situation is created when collapse is produced simultaneously throughout the forest in a pattern of irregularly dispersed gaps of greater magnitude : These more important gaps easily become centers from which further mortality is rapidly spreading. If then a more or less severe allogenic disturbance attacks the remaining dominant trees over a large area, generalized collapse can occur and result into real forest degradation.

Generalized collapse engenders completely new circumstances and environmental conditions, presenting greater opportunities for eventual recolonization of the denuded site by pioneers or early-succession species. The eventual return to the previous optimal phase is not excluded, but it will take much time. Otherwise, this kind of positive evolution requires that forest destruction is not accompanied by profound site modification, no other environmental changes occur and exogenous pressures of all kinds stay absent or remain mild over a long period.

Following the same line of thinking, sufficient argumentation can be found for the fact that forest degradation is far less tò fear during the transition phase and that the initial stages of forest development are, in terms of site functionality, the least vulnerable.

The greater species content of the forest in the earlier phases of its development and the quick occupation of released space by pioneers point in that direction. Equally important is the repeatedly observed phenomenon of simultaneous establishment of tolerant and intolerant tree species (Van Miegroet, 1983) on partially denuded sites.

Pioneer species grow faster in large gaps (Schulz, 1960; Baur, 1960; Whitmore, 1974). They can quickly restore some kind of forest situation with renewed control of the developing community over the site.

The relative resistance of the younger phases of forest development concurs with the more general opinion of Hollings (1973) that unstable communities are often the most resilient. They are likely to contain species well adapted to variable environmental conditions. Species, regularly subjected to a wide range of physical environmental pressures, are more likely to tolerate a novel stress than species, belonging to a constant environment (Connell & Orias, 1964; Slobodkin & Sanders, 1969; Thierry, 1982).

The type, intensity and rate of exogenous disturbances play an overruling role with regard to the situation in the terminal phases of forest development.

Disturbances could be considered as fairly 'normal' if their periodicity concords more or less with the average life expectancy (Runkle, 1985) of the dominant trees and if they do not prevent these dominants from reaching maximal attainable size limits.

In case of higher disturbance rates, the terminal phase will not reflect an optimal situation, to be characterized by the dominance of the tree species with the longest life span the site can carry. It will show, quite contrary, a different set of species, nearing the composition of the transitional phase with a mixture of tolerant and intolerant species in variable proportions, or even the later stages of the initial phase, with typical dominance of shorter-lived but fast growing pioneers.

If frequency and intensity of disturbance increase still further, a situation arrives where tree forms are no longer viable and dominance within the community switches from trees to shrubs and herbaceous life forms (Runkle, 1985). This type of forest degradation can persist for a very long time. It is the product of site-linked selection forces or due to regular human interference. Technical intervention and protective measures may be required to obtain and permeate more advanced stages of community development.

The commentary upon the model of forest development by Leibundgut (1970) is equally applicable to the models, described by Oliver (1981) and by Bormann & Likens (1979).

In the model of Oliver (1981) forest vulnerability to degradation is expected to increase from 'stand initiation' over 'stem exclusion stage' and 'understory reinitiation stage' to 'old-growth stage'.

In the later phases of forest development, first generation species are supposed to senesce and make place for more tolerant species where natural disturbance is rare or only occurs on a small scale (cfr. Closed circuit 'optimal phase - senescence - regeneration' as presented by Leibundgut, 1970). These tolerant elements also fill the gaps to replace fallen trees (Runkle, 1982). Where these replacements do not occur or when regeneration does not occur within a reasonable delay after disturbance, the ecosystem stagnates and ultimate degradation becomes unavoidable (Rowe, 1960).

Fundamentally the same course of events is described by Bormann & Likens (1979). The forest is considered least vulnerable during the 'reorganisation phase ' and the first half of the 'aggradation phase'. In the second part of 'aggradation', the till then dominant species begin to loose their grip on the community for reasons still poorly understood : Understory species are able to establish, but the danger for degradation is never absent. It is however in the subsequent 'transition phase' (cfr. 'Uebergangswald' by Leibundgut, 1970) and in the 'steady-state situation' (cfr. 'Endwald' by Leibundgut, 1970) that degeneration and eventual degradation are only avoided if no serious allogenic disturbances take place.

The three models cover some common ground, but the model by Leibundgut (1970) is the most plausible from a silvicultural point of view. Leibundgut (1970) and Oliver (1981) hold pretty much the same opinion when they consider degradation as a consequence of distorted internal dynamics during the ultimate phase of forest development, resulting in failing regeneration. They do not reckon with the possibility of forest degradation in the earlier phases of its development, because they do not really take allogenic disturbance into consideration as an important agent of change. Bormann & Likens (1979), on the other hand, see a close link between forest degradation and external pressure.

Otherwise, there is a general consensus that the danger for degradation is maximal in forests with a gregarious type of development, especially if the greater part of the dominant canopy components are old or even over-aged. Increased global forest vulnerability in this case is due to the physiological characteristics of the older trees, representing the greater part of standing tree biomass (Diminished efficiency to transport water and minerals. Decaying root system, having to support a relatively high above-ground biomass. Decreasing rate of photosynthetic biomass to total biomass).

Gregariousness has also spatial consequences. Larger gaps are made in the later phases of forest development when older dominant trees start to die, one after the other, within a relatively short time. The primary gaps are extended rather rapidly. The danger for insufficient regeneration and even degradation increases as larger areas are released and consequently exposed to eternal stress

Under most circumstances, even mild disturbances can have degenerative effects if they are not quickly nullified by the establishment of new seedlings and/or the emergence of suppressed elements with a good potential for dominance. Rapid reoccupation of the site is, quite evidently, still more needed if severe disturbances occur, opening up more space for imminent degradation.

Forest management and silvicultural treatment have to learn from these phenomena. Over-aged dominants, whatever their value should not be maintained indefinitively. They can cause a stagnation of dynamic development, much needed to keep the whole community in an optimal state of health, vitality and functionality. Induction of forest regeneration and stimulation of the reestablishment of late-succession species can start as soon as the optimal phases of forest evolution are attained.

2.3.4. Site and geographic situation

Some regions are more prone to exogenous disturbance than others. Labanauskas (1973) and Tamata (1977) made remarkable observations in this respect on the incidence of storm damage in the forest. Moreover, within an endangered region, storm damage is concentrated on poor sandy soils (Bazzigher, 1969),organic soils in Ireland (Gallagher, 1974), marshes (Labanauskas, 1973) and heavy loam and clay soils (Wangler, 1976).

Experiences of the same kind could be cited concerning the impact of avalanches, landslides, excessive snowfall, floods, fires, forest use and human influence in general.

They do, however, not provide unequivocal information on the direct relation between forest degradation and specific site conditions. Neither are they useful to explain the particular vulnerability of the forest on so-called 'extreme' sites.

It is rather simplistic to accept, without further proof, that communities in extreme conditions (very high or very low temperatures, high degree of aridity, poor soil structure, minimal biological soil activity, insufficient availability of water and minerals etc.) are more likely to be vulnerable as they often have a simple structure because of the extreme conditions (Bradshaw cited by Holdgate & Woodmann, 1979). Such an opinion is based on the perception of relative homogeneity and slow growth as possible indicators for increased vulnerability or a lower degree of individual and collective vitality.

This may be true on better sites with good growing conditions, where homogeneity can be related either to human influences, forest use and interventions to reduce the number of species for economic or technical reasons or to aging and increasing sensibility of older dominants with disturbed physiological functions and declining vitality. In both cases the potential for resilience and positive reaction against disturbance and perturbation diminishes. 'Slow growth', on the other hand, can only be considered as a danger sign if it descends beneath the average level to be expected normally at the given site, considering the species, the age of the trees and the developmental forest phase.

On real extreme site, for instance in boreal and alpine regions, relative forest homogeneity is the normal result of natural selection under nearly permanent conditions of severe environmental stress. Slow growth can be explained there by the short period of intense physiological activity due to the low temperatures of air and soil, as well as by the modest reserves of available nutrients, restricted turnover of minerals and excessively low biological soil activity. Iversen (1969) holds, nevertheless, the opinion that, even on extreme and poor sites, progressive acidification of base-poor soils could, over thousands of years, produce profound changes in the nutrient-status of the exposed soil. Such a development could lead to reduced resistance of the dominant species, with enhanced vulnerability of the system as a whole as an ultimate consequence. It could also be sufficient to provoke gradual replacement of demanding species such as ash and lime in Northern Europe by less demanding species such as birch. However, such a replacement, even if it is caused by progressive soil impoverishment, modifies the community and has undeniable ecological consequences, does not necessarily imply increased vulnerability of the modified ecosystem.

Not less important is the fact that the same type of disturbance does not always and everywhere generate identical processes. Equally, must apparently identical developments not have necessarily the same origins. Forest podzols in Scandinavia are morphologically similar to some heathland podzols, but the latter are, chemically, more acid and their rate of turnover of organic matter is much lower (Perrin, 1964; Tamm & Holmann, 1967). Denslow (1985) cites the case of the Canadian boreal forest, where fire, considered as an autogenic disturbance, and logging, clearly an allogenic disturbance, initiate succession patterns similar to those following budworm outbreaks.

The undeniable link between geographic situation and disturbance, as well as the relation between geographical situation and catastrophic occurrences in some locations, lend some support to the proposal by Drury & Nisbet (1971) to consider the physical site as fundamentally unstable. This opinion emphasizes the importance of continual change and promotes a kinetic view on forest development.

Treefall occurs more on slopes than on level ground (Tourquebiau, 1981); the life expectancy of most tree species is there also considerably shorter (Putz & Milton, 1982). Treefall increases with altitude in Ecuador (Oldeman, 1978). It is higher in swampy situations than on the uplands in Costa Rica (Hartshorn, 1978). In some forests, trees are unstable on fertile soils because of their shallow root system, but less prone to fall on infertile, but well-drained soils, where they root deeper.

Rain forests, where large scale succession is nearly always non-existent, can be subjected to large-scale disturbances by landslides and hurricanes in specific conditions, due to site topography and geographic location (Whitmore, 1975; Crow, 1980).

It is known for a fact that stormwinds can have catastrophic consequences for the forests in countries bordering the North Atlantic (Catastrophic forest destructions of january-february 1990). Tornados are highly destructive, often beyond immediate rehabilitation of the forest, in Central America, the Carribeans and the south-eastern states of the United States.

Earthquakes and volcanism are other examples of catastrophic disturbances, linked to a particular geographic situation.

Eleven earthquakes with an intensity of at least 6.0 on the Richter scale occurred in may 1960 in the Lake District of southern Chili. They caused avalanches, landslides and mudflows in the Andes over an area of 300 by 1000 km. In the province of Valdivia alone, they devastated 25 000 ha of excellent forest (Veblen & Ashton, 1978; Veblen, 1985).

Entire regions of the same district were repeatedly perturbed by catastrophic volcanic eruptions over a long period (Martin, 1923; Casertano, 1963). Between 1640 and 1979, 56 eruptions from 13 volcanoes destroyed thousands of hectares of forest on the mountain flanks or covered them with ashes. Eruptions from the Peyehue in 1907, 1921-22, 1926 and 1960 covered 22 000 ha with pumice sand and gravel, in 1960 with a layer of at least 5 cm (Wright & Mella, 1963).

Fires, following volcanic eruptions, quite often complete forest destruction.

In regions without volcanic activity, forest fires can have a particular significance. They are sometimes linked with intensive forest use and human presence. They can, however, also indicate a close relationship between geographic situation and forest vulnerability, especially in regions where direct human impact is restricted.

Forest fires are universal and frequent in the boreal forest, to such a degree that they are considered by Cottam (1981) and Van Cleve & Viereck (1981) as having mostly natural causes. They are accepted occasionally as part of the natural environment and not as devastating disturbances in a strict sense. Their role in spontaneous forest regeneration can be tremendous and hence their systematic use as a reforestation technique by some specific types of forest management.

In areas suffering from droughts and in arid regions, where mineral uptake is difficult because of the lack of water in the soil, fires cause serious forest and ecological damage. They can even provoke degradation of already poor sclerophyllous vegetations with a low mineral content in their tissues (Graves, 1981).

A last and most obvious example of geographic linkage is the regular occurrence of avalanches, landslides and mudflows in mountainous regions and the incidence of forest devastating floods on flatlands and in valleys.

3. REHABILITATION

The restoration of a degraded forest ecosystem is often misjudged and, too optimistically, considered as a purely technical problem, easy to solve if the right means are available. It is, quite contrary, an extremely difficult enterprise, complicated by the interacting processes, causing degradation, which are not always correctly understood and interpreted.

To restore a forest ecosystem, it remains essential to understand the processes, by which it became degraded (Dimbleby/Holdgate, 1978. Cfr. 'Stability') and to locate 'degradation' and "rehabilitation' in the right developmental context.

Forest degradation can be the result of two essentially different types of development, which, consequently, require a different approach to restoration, although both reveal the importance of essential economic and social aspects (Cfr. Köpp, 1978; Holdgate, 1978) :

- The reversal of forest degradation, caused by long-time historical development, requires a predominantly political approach, because it has to do with social development, changes in land and forest use and especially a continually growing demand for certain specific products and services.

- The reversal of forest degradation, caused by short-time development requires a predominantly technical approach, because it has much to do with environmental change and its rectification.

In second place, it must be made clear what the aims and realistic possibilities of restoration are. Several options are open, each expressing a different view on rehabilitation, requiring an essentially different approach and different types of corrective or reconstructive intervention :

- Restoration of the outer limits of integrity of the forest ecosystem involves the recreation of a self-sustaining 'producer-consumer-decomposer'-system (Holdgate, 1978). It reflects a conservationist approach, sometimes going out from the disputable assumption that the pre-degradation situation can be completely reconstructed, which is highly improbable in most cases.

- Restoration of optimal functionality of the forest reflects a more ecological approach, especially if no particular, but a global ecosystem-benefit is the principal aim of the operation.

- Restoration of biological content or the promotion of certain desirable floristic or faunistic elements can be equated with a biological approach. It, undoubtedly, has some restricted conservationist aspects, but does not always result in maximal ecosystem functionality.

- Restoration of valuable economic productions or redevelopment of services stands for a more exploitative approach with an undeniable social and economic background.

The exclusively exploitative approach was, for a long time, the principal course of action taken by forest management, quite often with poor or only temporal positive effects. The modernistic silvicultural concept, based on bio-ecological considerations (Arbeitsgemeinschaft für naturgemässe Waldwirtschaft; Swiss school of Schädelin-Leibundgut; 'Pro Silva'-movement in Europe) tries to combine these different approaches in a pluralistic view on sustained and global forest utility.

Nevertheless and under all circumstances, any intervention to revert forest degradation must go out from the reality of disturbance, particularly from the close links between forest vulnerability and site conditions.

From a practical point of view, restoration of a degraded forest has two principal aspects: Restoration of the tree population(s) basic to restoration of the more complex producer-consumer-decomposer relationships, and reveral of undesirable site modifications brought about by disturbance. Attempting such a reversal, it is essential to recognize that rehabilitation and degradation rest on the same basic assumptions:

1° The direct consequences of disturbance and the changes it provokes.

2° The specifics of the relationship between site and man, expressed by demographic particularities, forest use and human influence on the forest ecosystem as a whole.

3° The two-directional feed-back between site and living community.

At any case, it remains fundamental not to consider rehabilitation as the exact opposite of degradation. Rehabilitation can tend to reconstruct a living community and relationships, identical or equivalent to those governing the pre-disturbance forest ecosystem.

It can, however, also result in a new situation, different under many aspects from the pre-disturbance state, but not less valuable from an ecological and functional point of view.

3.1. Direct consequences of disturbance

If a relation exists between forest succession and nutrient cycling, it is logical to reckon with a relation between disturbances, which modify water flow and nutrient cycling, and degradation of a forest ecosystem. Rehabilitation must tend to restore cycling, especially the normal water flow, which is the driving force behind ecological change Holdgate, 1978) as it determines the state and modifications of resources availability. Immediate restoration results may be misleading because of the increase of mineral resources, directly after disturbance, that disappears when new biomass is produced, water uptake and transpiration rise again and decomposition of organical matter is slowed down, following the decrease of direct soil insolation.

Therefore a study of the changes in the flow of water, energy and minerals is necessary to understand degradation and undertake eventual restoration, particularly because these phenomena help to evaluate the course of events during recolonization of the site.

First colonists enjoy the relatively greatest supply of nutrients with extremely important consequences for subsequent forest development :

- Early arrival gives competitive advantages and can partially explain subsequent dominant status of particular tree species either tolerant or intolerant (Van Miegroet, 1983). Excellent provisioning circumstances even enable first settlers to survive and grow well under sub-optimal conditions of light radiation.

- Early arrival is particularly important to species with higher light demands when only small patches are liberated and the increase in resources availability remains rather low because of restricted biomass destruction and limited increase of soil insolation, with reduced stimulation of the decomposition of organic matter as a direct consequence.

- In case of an important release of resources on sites where the recolonization pressure is high, due to the presence in the immediate neighborhood of pioneers with a considerable potential for seed production or to excellent conditions for vegetative regrowth, the period of increased availability of resources, hence the period for quick forest regeneration, can be very short. Oliver (1981) is convinced that the establishment of seedlings of many species is often limited to a brief period following disturbance (1 to 5 years), whenever rehabilitation occurs rapidly.

These considerations do not apply completely in the case of severe disturbances, with a large spatial impact and the quick release of resources over a vast area. Reestablishment of biomass is then retarded for evident reasons and the release of resources is not sufficiently checked by quick recolonization or regrowth. Physical degradation of the site (Nye & Greenland, 1964) and profound disruption of mineral cycling (Christensen, 1977) are the inevitable consequences of such a development, leading often to a nearly irreversible situation.

Silvicultural treatment and forest management must keep these processes in mind before deciding on any intervention, especially when the forest has reached a stage where its renewal is imminent or its transformation judged necessary.

Clearcutting of the forest over a larger area is to be avoided unconditionally. It always provokes site deterioration, mostly irreversible or requiring a verily long time to restore nutrient cycling and water flow to pre-intervention conditions.

If group regeneration is preferred, individual released space units should never be larger than absolutely necessary to meet the basic light requirements of the most desirable tree species, suitable for that location. From the ecological point of view, regeneration over small patches, unevenly dispersed in time and space, seems to be the best solution. A certain degree of protection given to new seedlings by temporarily remaining dominants can have a most positive effect.

The ecological concept of silviculture with primary attention for forest maintenance in a state of sustained yield of products and services, must necessarily opt for longer regeneration periods for the whole forest. They cause less frequent and less profound disruptions of mineral cycling, allow better control over water movements and promote persistence and dominance of long-lived late-succession species.

A sound balance must be found between ecological and conservationist desirability, managerial possibilities and technical potential.

It is, however, in no case sufficient to observe only certain general rules and recommendations concerning site modification caused by disturbances or by silvicultural interventions, to be considered as controlled and induced disturbances. A thorough analysis is needed as it is important to keep track of particular processes and their specific impact on sites, species and living communities.

First of all should be noted, that increased decomposition of organic matter after disturbance is accompanied by increased N-mineralization (Matson & Vitousek, 1981). Simultaneously, sub-soil erosion is initiated by the intensification of sub-soil water movements. Nutrient losses follow as the consequence of horizontal transportation of minerals, leaching and denitrification (Swift et al., 1975) on sites where the superficial organic layer disappears rapidly after the increase of insolation, caused by the release of space.

Borman & Likens (1979) believe that net decline of organic matter can endure for several years after primary production and nutrient uptake have returned to pre-disturbance level. This phenomenon is most outspoken where pioneers colonize the released space because their own organic material also decomposes quickly (Mellilo et al., 1982). This could be an accessory argument in favor of tolerant species, used to correct forest degradation or forest transformation.

As a matter of consequence, forests on soils with a low content of organic matter or with a high degree of biological soil activity, are most vulnerable to degradation following disturbance or excessive silvicultural intervention. N-losses are greatest and occur most rapidly on fertile soils (Wiklander, 1981), whereas N-immobilisation and delays in nitrification are more substantial on sites with a limited N-reserve in the soil immediately before disturbance (Vitousek et al., 1982).

N-losses as a possible cause of forest degradation are to be taken seriously, as the amount of nitrogen, cycled annually, can reach 10 to 100 times the amount of the N-pool (Roswall, 1976).

Less important is the possibility of direct loss of phosphorus. This element has no gas phase and increased leachings after disturbance are rare. Phosphor is immobilized by decomposers. It is also extremely immobile in the soil (Nye & Tinker, 1977), where it forms insoluble complexes with Ca at high pH-level and with Al, Fe and Mn at low pH-level.

Disturbances can, on the other hand, indirectly initiate considerable losses of Ca^{++},Mg^{++} and K^{+} due to deplacements of cations in soil solutions to maintain electrochemical neutrality (Bormann & Likens, 1979).

The parameter by which to measure potential vulnerability to degradation of a forest through modifications in soil chemistry seems to be the economies of nitrogen and phosphor. Phosphor is supposed to be the eventual growth-limiting factor in the tropics; nitrogen is more important in the boreal forest (Vitousek, 1984); in all other transitional forest types the relative importance of these elements is variable.

Predictions based on potential vulnerability of a forest, deduced from chemical soil conditions, require extreme caution. Most phosphor and nitrogen in the soils is not immediately available to organisms. The correlation between nutrient uptake and a decrease in pool content is not proven beyond doubt (Powers, 1980). Competition for a limiting nutrient can cause an extremely rapid turnover (Vitousek, 1985). Ulrich (1978) is however convinced that the critical steps toward degradation of the soil and, subsequently, of the forest, is the loss of phosphorus and rapid leaching of nitrogen.

It also stands to reason that all these phenomena must be interpreted against the background of geographic conditions, under which they occur.

It is logical to accept that the risks for forest degradation are greater on the more fertile soils. However, base-poor soils can also be vulnerable, especially if they are well drained or situated in high-rainfall areas. Their deterioration can provoke rapid forest degradation.

Even partial clearance of the forest by disturbance or exploitation can create imbalances, not in the least through destruction of a root system, that, up to that moment, was able to ascertain some degree of superficial soil fertility by bringing up minerals from deeper soil horizons in sufficient quantity to sustain modest forest growth.

The leaching process becomes more intense on acid soils, which get more and more acid and depleted of plant nutrients (Dimbleby, 1978).

Repeated disturbances can, over a longer period, prevent the return of pre-disturbance forest conditions. Even the return of any kind of forest state can become impossible as soon as a certain level of depletion is attained.

3.2. Human influence

Taking all these occurrences, phenomena and processes in consideration, it soon becomes clear that the relative vulnerability of any forest is influenced to a variable degree by human presence, demographic dynamics, social and technical development, available natural resources, land use, types of human activity and their spatial distribution. In many cases the human factor is, directly or indirectly, the main cause of forest degradation as recent developments increasingly indicate. Very often some kind of synergism can be observed between natural disturbances and human interventions, creating a most dangerous situation or resulting in catastrophic forest devastation and environmental deterioration.

Because of the importance of human influence, forest vulnerability is not to be considered exclusively as a bio-ecological concept. Forest degradation belongs also to the realm of forest policy : It has much to do with ethics and the regulation of human conduct.

In this context it is further essential to recognize that human actions not only modify the biological and physical components of forest and environment, but they also alter the nature and rate of their interactions. Not only the immediate results of human intervention must be studied, but also the processes they stimulate. The ultimate repercussions of all alterations must be analyzed with their reciprocal connections in mind. Scientists, discussing this interacting system of biological and physical components, mostly omit many components of the social context and the responses of the human community, which, in their turn, are able to modify human actions (Holdgate, 1978).

Environmental modification, inclusive forest degradation and deforestation, has far reaching effects. It provokes new human intervention with a potential for positive or negative consequences. Therefore the social context must be rightly understood to work out solutions and explain scientific options (Holdgate, 1978).

A coherent list of human influences on the environment with direct and indirect consequences for the corresponding ecosystems, has been made by van der Maarel (1978). The system allows to assess the position of the forest and the imminent danger of its degradation.

In this scheme the changes, generated by human activities, in the abiotic and biotic geosphere components (substrate; soil/structure; water; nutrition; plants; vegetation; animals) are considered. They are ordered in a sequence corresponding to a more general hierarchy of spheres, determined by the total influence each sphere has on the other spheres (van der Maarel & Vellema, 1975).

Holdgate (1978) holds that biological modifiers such as cropping populations (= cutting of trees, hunting, exploitation of forest products etc.), regulation of species density and genetic manipulations produce a direct repercussion on the ecosystem. But this is exactly what silvicultural treatment does to the forest when executing thinnings, inducing stand regeneration, reducing the number of species, proceeding to selection, introducing alien elements. Applied research has paid great attention to the impact of these technical interventions on the tree population and its dominant components, but neglected to study the changes provoked throughout the global forest ecosystem and in the immediate neighborhood of the treated forest.

Most physical modifiers (excavation; construction; temperature change; water flow) also generate direct alteration. Modification of the physical properties of the atmosphere primarily induces climatic change, which, in turn, has an impact on the ecosystem.

Chemical modifiers on the other hand, have nearly always an indirect effect. Modification of the atmospheric composition influences the (forest) ecosystem via primary climatic change; fertilizers and sewage act via modified water composition; toxic materials extend their influence via deterioration of water composition or soil conditions.

Nearly all environmental modifiers can be used as indicators for potential ecosystem degradation i.c. forest degradation.

Direct influences are more to fear in the short time, whereas indirect influences, which work much slower, may have longer-lasting repercussions on the forest ecosystem.

This conviction resides on the assumption that forest vulnerability is two-sided. On one side, the state of the forest ecosystem is determined by composition, structure, texture, age, location, site properties and socio-political environment. On the other hand is to be reckoned with the nature of exogenous disturbance or perturbation, characterized by type, intensity and frequency. In this dualistic relationship, human society can be a stabilizing or a destabilizing factor by its own decision.

3.3. Site / Living community

One of the more remarkable consequences of disturbance is the intense feed-back between site and living community immediately after the disturbance occurs. The main force behind this feed-back are the site modifications, generated by the disturbance.

If these modifications are mild, the chances for rehabilitation of the living community and, consequently, of the complete forest ecosystem can be considerable, provided certain basic conditions are met. An essential condition is that the community must be able to regain complete control over the site within a relatively short time and that plant nutrient uptake can quickly return to pre-disturbance level. In the opinion of Gholz (1980) regaining complete control should not take more than 2 to 5 years. The possibility of quick recovery depends upon three conditions :

- The remaining forest vegetation did not suffer too much from inhibition following acute exposure.
- The seed sources are not completely destroyed.
- Site conditions are not modified to the degree where reoccupation of the released space by the original forest vegetation or by any forest vegetation at all, has become impossible.

In the case of important or severe environmental modifications, rehabilitation may be retarded or practically excluded. One of the reasons may be that the surviving stand elements remain in a state of shock for a longer time and/or that regrowth is seriously hindered. If control of the community over the site is not established soon enough to prevent further loss of fertility, soil degradation sets in with total forest degradation as a possible and ultimate consequence.

Rehabilitation of a disturbed forest ecosystem may occur spontaneously, but, even under optimal conditions, it is not always sure that a complete reversal to the previous situation will take place.

Complete reversal to predisturbance conditions has the best changes in case fairly mild disturbances attack one of the earlier stages of forest development and a sufficient number of quick growing pioneers is available for rapid resettlement of released space. If later developmental stages are subjected to severe disturbance, complete spontaneous rehabilitation can take a very long time as late-succession species do not always possess the potential to colonize the site immediately after the release of space.

Quite a different situation arises after disturbances occur on sites with high species resources. In this case it is far from sure that the pre-disturbance situation can be restored completely, at least as far as species and their functional position are concerned. Equivalent species combinations may arise, that, at least, provide the same degree of ecosystem stability and exert the same amount of site control as the pre-disturbance community. This type of forest rehabilitation concurs with the type of spontaneous regeneration, observed by Aubréville (1965) in the tropical rain forest of Africa and which he considered as basic in formulating his mosaic theory.

It must, however, be kept in mind that spontaneous forest rehabilitation after more or less advanced degradation, whatever the specific cause, becomes increasingly rare. The main reasons for inhibited recovery are the increase and differentiation of human influences, due to demographic evolution, increased mobility of man and technological progress. As a consequence, and quite paradoxically, rehabilitation requires more and more human intervention to restore the physical and biological features of a degraded forest ecosystem. A greater input is also necessary to stimulate the biological processes, that must make restoration permanent.

4. A REHABILITATION STRATEGY

The rehabilitation of a deteriorated forest ecosystem is a highly complicated, delicate and problematic undertaking. It does not suffice to plough the soil to restore its physical condition, to apply fertilizers to obtain excellent nutritional conditions, to plant trees of good provenance and cultural quality to recreate the disappeared living community.

A sound strategy for the restoration of degraded forest ecosystems must be two-sided under at least two principal aspects:

- It must be directed toward disturbance itself and, at the same time, toward the possible or actual victim of disturbance.
- It must conceive interventions for the restoration of a lost, but desirable

situation, but also pay due attention to what can be done to avoid disturbances, diminish their effects and control their workings.

Such a double strategy requires a double approach. It has to find out what makes forests vulnerable, but also what makes them resistant in a general and specific way to disturbance. For such an analysis the study of present patterns, including the patterns for actual and potential dereliction is essential. An acceptable definition of ecological capability is required, including the capability of the environment for restoration (Holdgate, 1978). A thorough analysis of socio-political and economic conditions is most useful, as the increasingly more dangerous agents of actual forest destabilisation and ecosystem disturbance are of human origin. Their effective control requires educational action, political intervention and applied legislation as the concretisation of an adopted forest policy.

Planning and execution of rehabilitation must consider certain stages and priorities, deduced from and complementing some basic principles formulated by Holdgate (1978):

- Restoration of the physical structure,chemical composition and biological functions of the soil is a priority whenever serious soil damage is observed. This kind of restoration is not attainable within a relatively short time. All interventions with a potential for negative influence on site and environment (manuring, fertilizing, use of soil conditioners,ploughing etc.) are to be rejected. Increase of biological activity in the soil will only develop gradually as the reconstruction of the living community progresses. Restoration of the tree population(s) is but a step in this evolution.

- Improvement of the physical and chemical features of water and waterflow can be very much needed. The input of alien material into the soil can have negative effects in this respect. All measures should tend to promote quick creation of a soil covering community of trees and other floristic elements, able to gradually take control over the site, reducing superficial waterflow and restoring water storage capacities.

- From the start it may be important to pay attention to the rehabilitation of the producer-consumer system, more particularly to gain control over the consumer world in the early and more critical phases of restoration.

- It is necessary to recognize the particularities of the situation arising when spontaneous recolonization of the site by tree species is retarded or does not occur at all within a reasonable time. Then a dilemma is created. Long-lasting denudation of the site may have serious ecological consequences and, eventually, make degradation irreversible under certain aspects. Such a situation requires technical intervention with, possibly, undesirable environmental consequences. The best solution in this case could be to replant the site artificially, but exclusively using autochtonous material or tree species that were dominant in pre-disturbance time. Wider spacing is advisable. It produces a partial soil cover, maintaining sufficient free space to give spontaneous accessory recolonization a chance. Soil and site modification must be avoided or restricted to the absolute minimum. The use of fertilizers or biocides is out of question.

Some of the measures, necessary to obtain rehabilitation, belong to the realm of general environmental policy, to be decided upon by political or administrative authorities of the higher echelon.

Such an authority is not always directly interested in localized problems, nor sufficiently convinced of the role of any forest in the promotion and maintenance of ecological stability. The political world does not always react quickly by formulating a suitable legislation, as it has to reckon with opposition from different sides against an environmental policy, judged too restrictive.

Pending political decisions on soil, water and natural resources conservation, which should create the real base for all ecosystem protection and the reversal of most undesirable developments, it is advisable to pay primary attention to the other side of the forest protection strategy : the forest itself and the measures to avoid disturbances, keep them under control and reduce their effects.

Mlinsek (1990; unpublished manuscript) has laid down the basic principle for a sound strategy of prevention. He recommends systematic promotion of forest stability, which he considers as the quality of a forest to remain vital and to act, over a long period of time and under varying conditions of stress, as an excellent agent for the storage of (an optimal quantity of) energy. Forest stability, thus conceived, has two principal components :

- Genetic variation and a (current) maximal number of vital elements, composing the tree populations.

- A sufficient number of spatially well distributed carriers (individual trees or tree clusters) of mechanical stability.

Both components are essential to create natural (or ecological) stability, which, in turn, is basic to economic forest stability.

Mlinsek (1990) is convinced that survival is the driving force behind most biological (and ecological) processes. To this end, he refers to recent research in the field of molecular biology and immunology : The formation of a protective wall around a certain mass of organic matter was the first step toward and the essential perquisite for the formation of the living cell. All living systems and organisms developed mechanisms for protection (and auto-regulation) in the course of their evolution.

This theoretical approach allows numerous deductions and opens up a wide field of speculation on the course to be taken to enhance forest resistance and to rehabilitate it after disturbance and eventual degradation.

First of all, it is essential to promote the development of rich populations of trees species, that can grow and regenerate on the given site, or to maintain them by all means if they are already present.
Artificial forest homogenization must be rejected, especially if allogenous tree species are used to this end. It endangers bio-ecological forest stability and, ultimately, also economic stability, not in the least because an ever growing input of energy is required to attain a pre-conceived level of timber production.

In second place, timely recognizance of the most valuable elements within a population is very important. Their real value is determined by their degree of functionality within the living system and their role in maintaining global stability and internal protection. Forest treatment must never aim at isolation of these elite-elements, but must be conceived to create optimal micro-environmental conditions for their development in service of the community.
Selection of value-carriers is never definitive and must be repeated periodically, according to the principles of forest treatment formulated by Schädelin (1942) and Leibundgut (1966). The rationale behind this option is the observation that the forest is an essentially dynamic system : Even its best components can suffer through external pressure and from internal stress, diminishing their vitality or disrupting their function.

Elements, considered valuable from a genetical or even from a mere phenotypical point of view, are, if promoted to dominant status and maintained in that position, also the carriers of mechanical stability in most cases. They develop harmoniously and function as the core of tree clusters, that are essential to over-all mechanical forest stability.
Optimal spatial distribution of valuable trees and tree clusters produces optimal community stability. It can be realized by control over or induction, in due time, of the forest regeneration process. It should, however, be kept in mind that relief of one tree generation by another, whether spontaneous or provoked by technical intervention, always concurs with a period of developmental crisis, during which the danger for destabilisation is never imaginary.
To obtain good forest regeneration, a wide choice of possibilities exists, having to do with the choice of species, the (intended) duration of the regeneration period and the spatial extension of individual regeneration units :

- Each silvicultural intervention is an induced disturbance with ecological consequences and provoking environmental change. Planning transformation or regeneration of a forest, it is essential to know how far silvicultural intervention can go modifying the degree of density of a forest cover or uncovering a forest site, both in space and in time, without endangering the integrity of the forest ecosystem beyond reversal, not only with regard to tree populations, but also concerning food chains, water economy, energy exchange and nutrient reserves. Therefore, provoked change must be localized in time and/or space and may not transgress certain limits, defining the possibilities for restoration of the disturbed system.

- A permanent equilibrium must be established between the distribution in time and in space of regeneration, keeping the question of the choice of species constantly in mind.

- Forest regenerations, whether spontaneously occurring or induced by silvicultural management, always follow certain basic patterns, determined by the spatial extension of the individual regeneration units and the degree of maintained tree cover or lateral interception of direct light radiation

- Small regeneration units, in the most extreme situation restricted to the space liberated by the disappearance of a single dominant tree, further resettlement with longer-lived and more tolerant late-succession species, which, fundamentally, have a positive effect on forest stability. They lead to spatial dispersal of small patches of regeneration and lengthening of the regeneration period, up to the point where regeneration is a continual process and the regeneration period is nearing the average life expectancy of the dominant trees. This pattern corresponds to the type of silvicultural management, more or less realized in the selection forest (Plenterwald). It stands for a continual dynamic development, based on structural stability and warranted by a great number of well-dispersed clusters of trees, different in age and dimensions. The advantages of such a state are evident, but should not be exaggerated. Veblen (1985) concludes rightly that uncritical acceptance of the all-aged type of forest structure is based on lack of appreciation of natural disturbances.

- Larger regeneration units, in the most extreme situation extended to the space covered by the forest stand of even a whole forest, further colonization of released space by quick growing pioneers and less tolerant species with a relatively short life span. The danger for destabilisation and permanent degradation of site and forest increases with the extension of the denuded space. This pattern corresponds more or less to a management system, based on clearcutting. The regeneration period is very short. Quick resettlement promotes the creation of even-aged forest stands, whose inherent vulnerability for disturbance is greater.

- The maintenance of a certain degree of forest cover over the part of the site coming up for regeneration (and to be removed later on gradually or by a single intervention), has about the same effect as the reduction of the individual regeneration unit, but only as far as the choice of species is concerned. It favors resettlement with more tolerant species with a relatively high life expectancy. The subsequent forest structures and, consequently, the degree of internal forest stability are determined by the patterns of removal of the provisionally maintained forest cover. Quick removal promotes the creation of the even-aged forest; gradual removal over a fairly long period promotes the creation of uneven-aged forest structures.

- Technical intervention of silvicultural management can combine at will different levels of spatial extension of the regeneration plots with the duration of the regeneration period and the process of elimination of an eventually retained protecting forest cover. It thus becomes possible to conceive numerous patterns for forest treatment, transformation and regeneration. They are deduced from a combination of aspects of the four elementary management types and the pattern of forest regeneration that characterizes them :

    - Clearcutting system (Kahlschlagsystem).
    Maximal extension of regeneration space. Extremely short regeneration period. Promotion of intolerant tree species with relatively short life span. Even-aged forest stands. High degree of vulnerability.

    - Shelterwood system (Schirmschlagsystem).
    Maximal extension of regeneration space. Part of older forest cover maintained. Regeneration period of variable length. Species mixture possible, but with dominance of tolerant species with relatively high life expectancy. Restricted variability (age and dimensions of trees) in new stand. Fairly vulnerable to disturbance.

    - Group regeneration system (Femelschagsystem).
    Regeneration in groups, regularly dispersed in time and space.Lateral protection of regeneration. Maintenance of forest cover over groups possible for some time. Fairly long regeneration period. Mixture of species. Dominance of one or other species determined by adopted regeneration period, degree of density of lateral and upper cover, spatial extension of the group.
    Mixed forest (species, dimensions, age). Fairly resistent against exogenous disturbance.

- Selection forest system (Plenterwaldsystem).
  Individual regeneration or in very small patches. Continual regeneration, irregularly dispersed in time and space. Complete maintenance of old forest cover. Very long regeneration period, equal to or nearing length of life span of dominants. Dominance of tolerant species with high life span. All-aged forest with mixture of species, dimensions and ages. Very resistant against disturbances.

In the past, much debate was concentrated around the question which management type was most useful. Actually, the conviction is growing that no 'best' solution, to be adopted under all circumstances, exists. It is the responsibility of silviculture to work out the most logical and most suitable course of action, warranting, in each case separately, the creation and maintenance of an optimal forest state. Management must be able to reduce internal stress and to keep sufficient control over exogenous disturbance.

There is no general consensus over the utility of exogenous silvicultural intervention, occasionally rejected by some conservationists as too technical and artificial.

It must, nevertheless, be recognized that increasing human influences endanger the forest constantly and make it more dependent upon helping interventions to correct undesirable developments. The principal aim of silviculture ought to be the promotion and stimulation of the mechanisms for self-protection and internal regulation. They determine forest survival, but become gradually more disrupted everywhere as the direct result of the impact of global pollution, overexploitation of natural resources and generalized environmental degradation.

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