Growth Trends of Forests in Southern Germany

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Abstract

Results from leaf or needle loss inventories and from investigations on growth trends in German forests have been found to contradict one another: while surveys of leaf loss indicate that tree vitality is declining since the 1980s, growth developments of the main species show an upward tendency since the 1950s, even in forest stands with high leaf loss and lie, at present, considerably above yield table level. Remarkable growth trends are apparent in the network of long-term experimental plots, as evident from results from forest inventories in 1970/71 and 1987 and in growth data based on increment cores and from the stem analyses of some 10 000 trees. While the causes underlying growth trends have already been successfully investigated and subsequently much discussed there is as yet no comprehensive representation of increment levels and increment trends for German forest stands. With the present chapter, an attempt is made to make up for this shortcoming. In spruce stands (*Picea abies* [L.] Karst.) diminishing height and volume growth at higher elevations in the Middle Mountains and the Alps are in sharp contrast to improving growth trends in the lowlands, where annual height increment and volume growth reach about 250% of yield table levels. On pure soils, in particular, pine stands (*Pinus sylvestris* L.) show site improvement manifest in an increase in basal area and volume increment of, again, up to 250% of yield tables levels. Growth decline below the level of commonly used growth models occurs only when leaf loss exceeds 60%, but was found to be rather rare. Beech and oak (*Fagus sylvatica* L. and *Quercus petrea* Liebl.) show a similar increase in height growth, volume increment and standing volume since the 1950s, with maximum values far exceeding the range of yield tables. Both species seem to compensate for leaf loss by additional productivity in the remaining leaves and show no definite growth reactions even in heavily damaged stands (60-99 % leaf loss). Dieback in beech stands sets in only after long phases of disease, whereas it tends to occur rather abruptly in oak stands. For the past two decades repeated forest inventories in Bavaria have diagnosed an increase of 10 - 20% in standing volume and show that species-specific annual volume in-

European Forest Institute Research Report No. 5
Growth Trends in European Forests
Edited by H. Spiecker, K. Mielikäinen, M. Köhl and J. P. Skovsgaard

crement exceeds yield tables by 10-40%. Similar production levels and growth trends in other parts of Germany were recorded through the nationwide network of long-term experimental plots.

1. Growth Reduction and Stand Devastation in Smaller Forest Areas

Extensive studies on growth trends in German forest stands were conducted mainly on account of forest damage in regions subjected to strong immissions in the 1970s. A striking loss of foliage was diagnosed in the Harz Mountains, the Black Forest, the Alps and in the border mountains of North-East Bavaria. Growth and yield investigations concentrated on regions with the highest damage rate. There was, literally, a run on severely damaged stands to examine their specific growth development and the correlation between growth and foliage loss at different degrees of damage. These investigations on growth in damaged stands yielded an informative view on the reactions of different tree types to the effects of immissions (Athari and Kramer 1983; Kenk 1984; Pretzsch 1989; Röhle 1987; Schöpfer and Hradetzky 1984 and 1986; Utschig 1989).

1.1. Spruce Stands

Figure 1 shows the characteristic growth behaviour of spruce stands in North and East Bavaria related to varying degrees of damage. Depicted is the percentage basal area increment at a given degree of needle loss between 30 and 99% - in comparison to that of unaffected trees (0-level). The increment curves of the collectives are not represented as absolute figures but in relation to the average increment within a reference period (1959-1968); hence initial differences in increment level of the collectives can be eliminated. In a second step, the increment development of damaged trees (standardized with the help of the reference period) are compared to the standardized increment trend of undamaged trees. The result is the percental deviation in the increment behaviour of damaged trees from that to be expected under undisturbed conditions (Pretzsch and Utschig 1989). As Fig.1 shows, the real increment collapse starts in the second half of the 1970s. Increment losses amount to between 50 and 60% of the reference increment and, as expected, rise steeply with increasing needle loss.

This comparison of collectives, recommended by the German Association of Forestry Research Stations for the diagnosis of increment trends (DVFFA 1988), serves as a detailed analysis of the increment behaviour in damaged stands. Forest management, in particular, has a keen interest in the study of the deviation in increment behaviour of damaged stands from the growth behaviour depicted in yield tables. Figure 2 shows the growth reduction in damaged spruce stands of the Bavar-

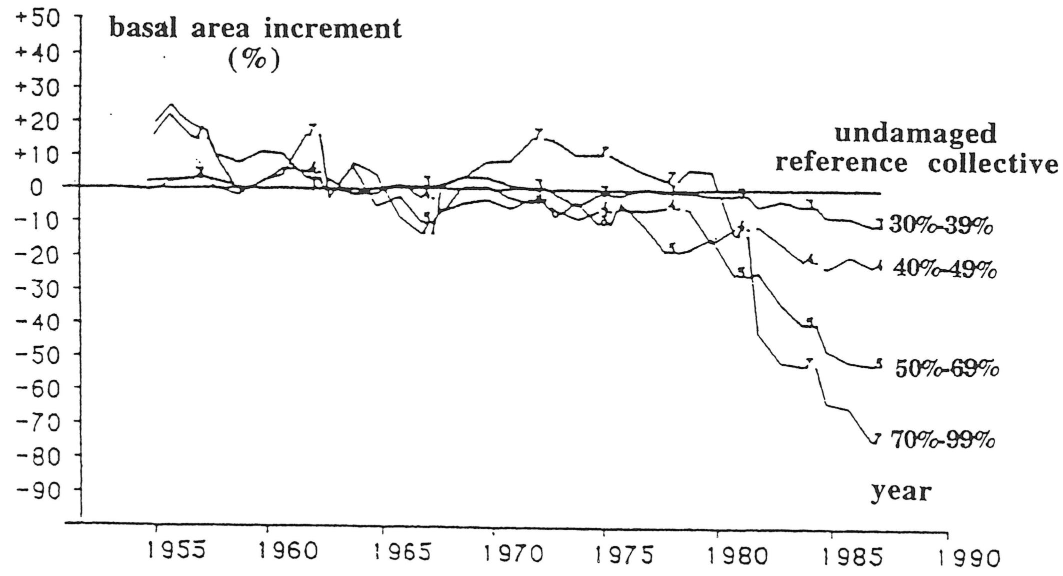


Fig. 1. Trend of annual basal area increment of damaged spruces in North and East Bavaria compared to the unaffected reference collective (0-level). In comparison to the reference collective (n=463), the increments have considerably decreased with increasing foliage loss since the 1970s. The collectives with needle losses of 30-39, 40-49, 50-69 and 70-99% comprise n=257, 75, 34 and 12 trees respectively.

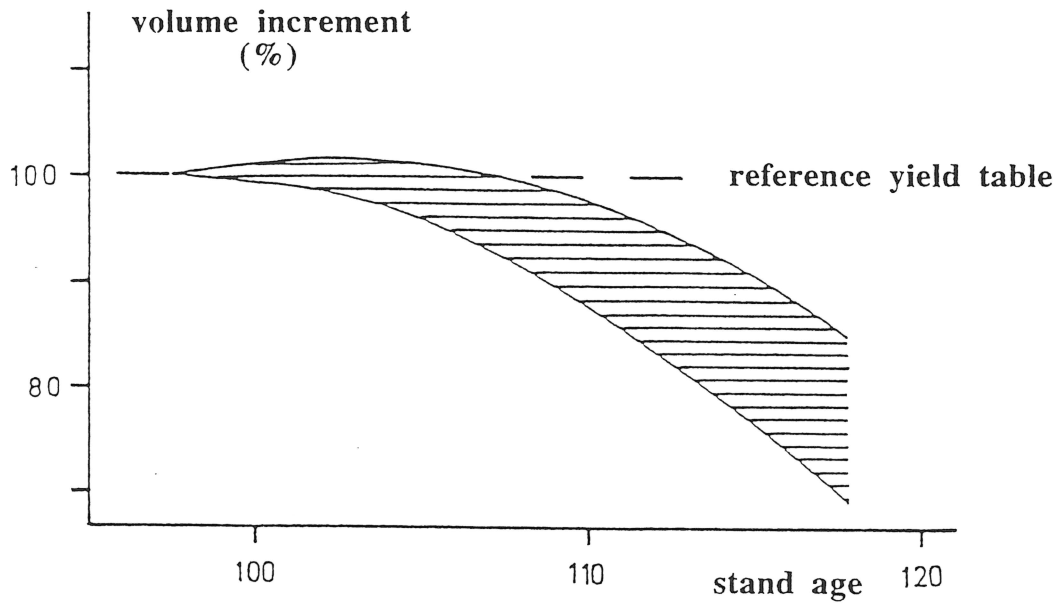


Fig. 2. Development of annual volume increment of damaged spruce stands in the Bavarian forest district Bodenmais compared to the yield table (according to Röhle 1987). Given is the volume increment (100% level). The upper border line of the hatched sector indicates increment loss calculated according to the table by von Guttenberg (1915); the lower border line indicates loss calculated according to the table by Assmann/Franz (1963).

ian forest district Bodenmais according to investigations conducted by Röhle (1987). The increment of stand volume on experimental areas in the border mountains of North-East Bavaria is compared with the growth curves of yield tables (100% level), with tables by Assmann/Franz (1963) and von Guttenberg (1915) used as reference. A comparison between the real increment trends on the experimental areas and yield table values shows that growth rates reached the level of the yield tables at the beginning of the observed growth period, i.e. in the 1960s. In the following years growth rates were significantly reduced. Present growth losses caused by forest damage amount to between 15 and 30% - according to the reference table used. This kind of growth reduction (mostly caused by immission) and the above negative deviations from values to be expected from yield tables cast doubt on whether yield tables are really effective as basic instruments in forest planning. It is well known that similar increment depressions are no occasional phenomena in single spruce stands. At high elevations in the German Middle Mountains, with a high influx of air pollution, all main tree species have, with regional and species-specific differences of course, shown similar reactions during the past 10 to 20 years (Schöpfer and Hradetzky 1984).

1.2. Pine Stands

The growth behaviour of damaged pine stands is comparable to that of damaged spruce: Increment collapse since the 1970s, moderate or strong damage including basal area increment loss up to 50%, and, with heavy needle loss as the prerequisite,

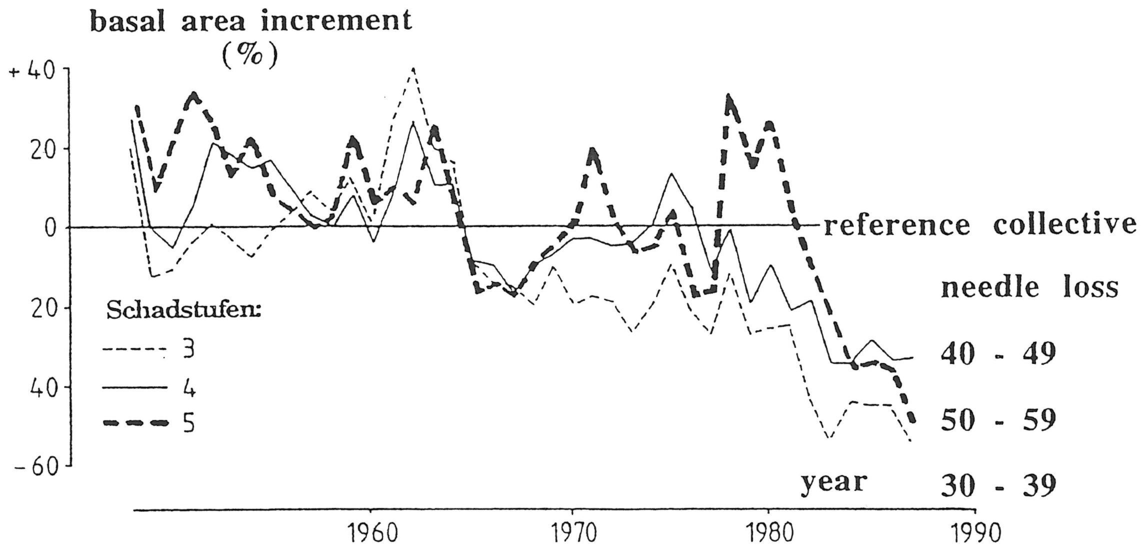


Fig. 3. Development of the current annual basal area increment of damaged pine stands in the forest district Selb in the Fichtelgebirge in relation to growth behaviour of undamaged trees (0-level). Since the mid-1970s, trees of all damage degrees (needle loss between 30 and 59 %) have suffered considerable increment loss (Pretzsch and Utschig 1989).

a correlation between needle density of crowns and increment behaviour (Fig. 3). The development of the basal area increment of damaged pines in the forest district Selb/ Fichtelgebirge shows a particularly serious increment depression and comparatively high increment loss. For pines, there appears to be a particularly high risk of confusing location-related phenotype with damage characteristics. Not in all instances does a close connection exist between estimated needle loss and measured increment development (Franz and Pretzsch 1988).

The comparison of increment trends in damaged pine stands with yield tables leads to some striking results: even damaged stands show growth behaviour that clearly exceeds values given in yield tables; only stands suffering from extreme damage do not come up to yield table expectations. In a schematic representation, Fig. 4 shows the increment behaviour of pine stands as observed on many locations found to suffer from a lack of nutrients in the past such as East German diluvium, Keuper and Jurassic soil and chalk sand soils in Bavaria and Baden-Württemberg. Since the 1950s many stands show an extremely high increment increase. The situation in healthy and damaged stands seems to be the following: in the 1950s and 1960s, i.e. before sustaining any damage, the growth level of stands today diagnosed as having been damaged is, in many cases, between 50 and 100% higher than yield table values. Even after damage began to take effect, growth rates were still higher than those indicated in the yield tables. Also, intensely damaged pine stands suffering from increment decreases between 20 and 30% (compared with unaffected stands) often show growth rates above the values of the yield table; it is only advanced disease that causes growth to drop below yield table level.

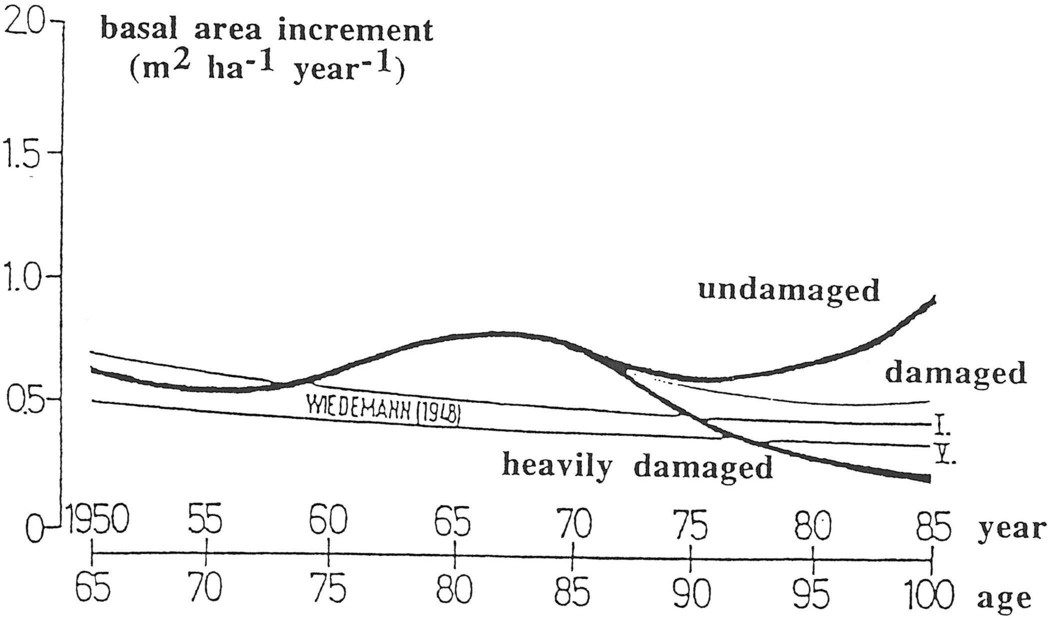


Fig. 4. Development of basal area increment of unaffected, damaged and heavily damaged stands in the Upper Palatinate compared to yield table values of Wiedemann (1948) for moderate thinning, in schematic representation (Pretzsch 1989).

1.3. Beech Stands

For beech, similar investigations failed to prove that a definite correlation exists between leaf loss and increment loss (Fig. 5). There is one exemplary representation of the development of the standardized basal area increment of beech trees in the forest district Kehlheim/Bavaria with and without foliage loss. Increment curves for single stems were related to average increment within the reference period (from 1933 to 1987). Figure 5 shows the following development: first, basal area increments have increased since the 1960s and 1970s, showing a development which is atypical of their age and emphasized by late accretion thinning. Second, this development can be considered a trend which is independent of diagnosed leaf loss. Third, there is no evident correlation between leaf loss and increment loss. Even leaf losses between 60 and 89% can lead to a basal area increment that exceeds that of trees without leaf loss. Compared to spruce, pine and fir, the species beech and oak behave in a manner totally different from the conventional model representation that foliage and increment are correlated.

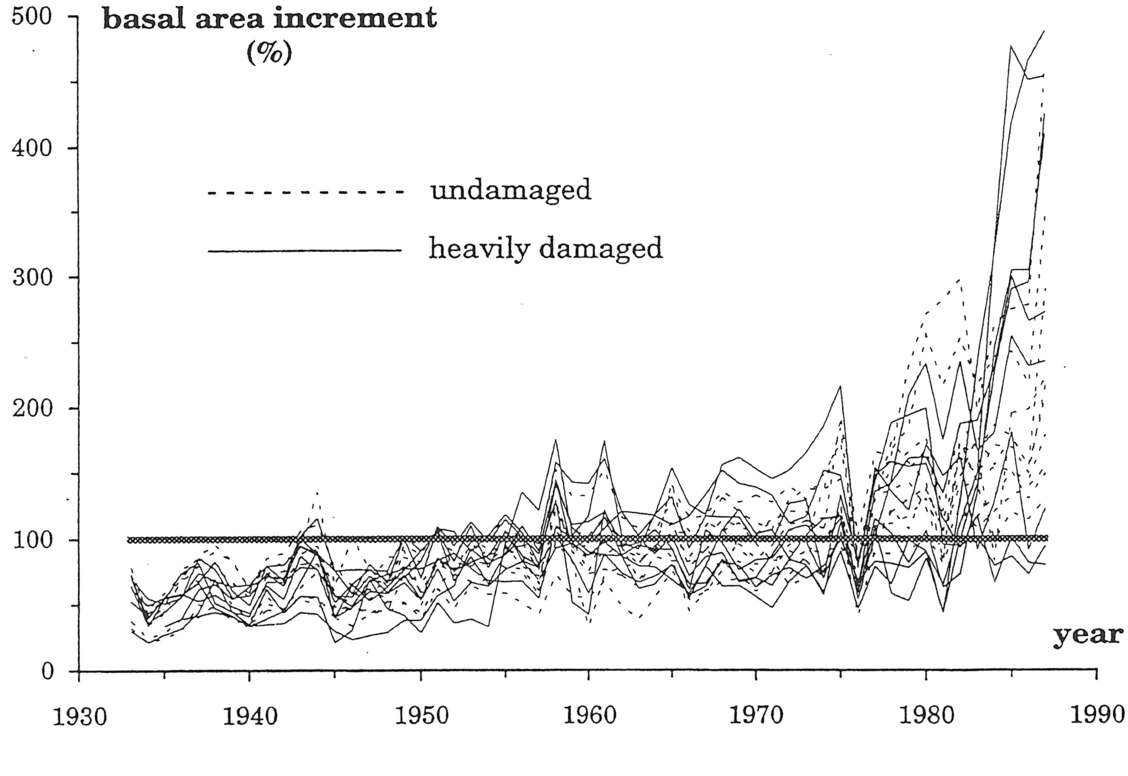


Fig. 5. Standardized development of basal area increment (reference period between 1933 and 1987) of beech suffering from moderate and high leaf loss in the Bavarian forest district Kelheim. Even with high foliage loss, there are no clear correlations between the phenotype and increment behaviour.

2. Widespread Observation of Increment Increase

2.1. Increment Reactions of Different Species on Long-Term Experimental Plots

Growth and yield investigations carried out in forest stands damaged by immissions have contributed towards the recognition that increment has developed along lines which appear to lie outside conventional models. Whenever increment loss had to be diagnosed and quantified, the following questions arose (Pretzsch 1987): what is the actual increment trend - the normal trend to be expected under undisturbed conditions? Are yield tables suitable for the correct assessment of increment depression? How is "normal" foliage density defined? To find answers to these questions, a series of healthy forest stands was observed and examined with regard to growth development. One fact, astonishing initially, proved a reflection of the general development: whereas considerable increment loss could be assessed in smaller forest regions heavily damaged by immissions, larger areas were shown to have developed increment increases for all main species. Since the 1960s and 1970s, it has become apparent that there is a highly positive deviation in increment and growth development from expected yield table values (Pretzsch 1992a; Röhle 1994; Schöpfer, Hradetzky and Kublin 1994).

2.2. Spruce Stands

The growth behaviour of spruce on experimental areas in the Bavarian Alps does not coincide with general developments, for the following reason: even in stands with moderate or more severe damage, increment is significantly above expected yield table values. In Garmisch-Partenkirchen (Fig. 6) increment growth is still consistently on the increase - despite the advanced age of the experimental area (149 years). Merely in the early 1970s was increment recorded to be retarded due to bad climatic conditions (severe droughts, particularly in 1974 and 1976). Increment development was nevertheless considerably above the level of yield tables by Assmann/Franz (1963) and von Guttenberg (1915). This kind of increment behaviour of alpine spruce (increment increase despite considerable needle loss) is basically different from diagnosed increment reactions (caused by forest damage) of spruce in other parts of Germany.

Comparisons of the volume increment recorded on 26 experimental units of the long-term plots Denklingen, Eglharting, Ottobeuren and Sachsenried/South Bavaria with the yield table shown in Fig. 7 indicate a development that is in many details, typical of more or less healthy spruce stands in Southern Bavaria (Röhle 1994). From the establishment of the experimental plots in 1880 up to the 1950s volume increment (influenced by climatic fluctuations) generally corresponded to yield table values. Since the 1960s volume increment has risen sharply, reaching levels of between 200 and 240% of the yield table, with the Assmann/Franz yield table (1963)

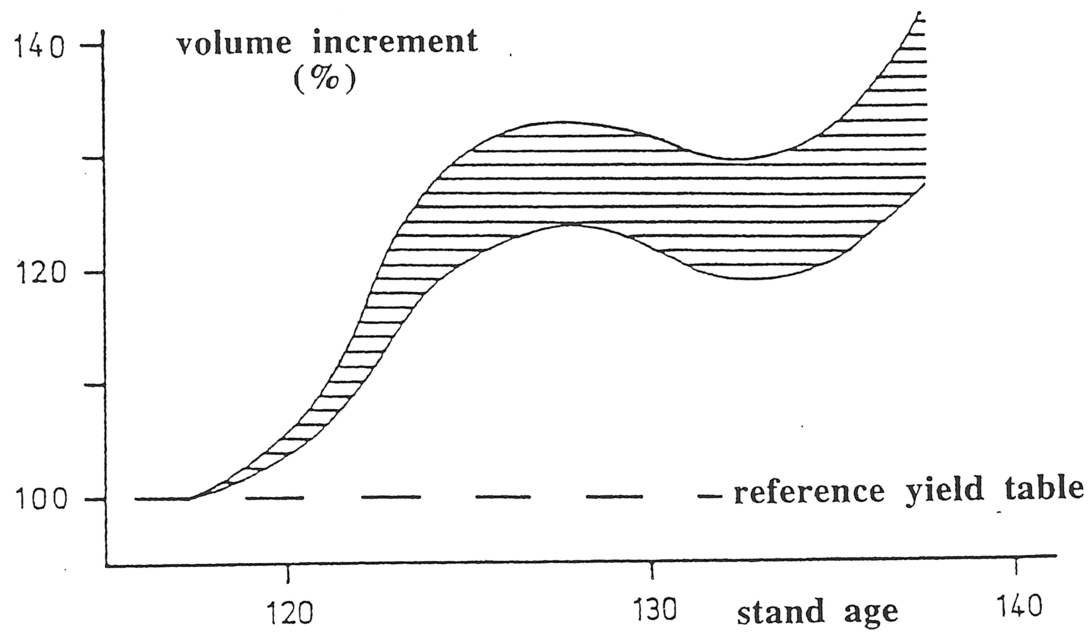


Fig. 6. Stand volume increment in percent of the standardized yield table increment for a damaged spruce stand in the forest district Garmisch-Partenkirchen in the Bavarian Alps (Röhle 1987). Indicated is the volume increment (100% level). The upper border line of the hatched sector indicates increment loss calculated according to the table developed by von Guttenberg (1915), the lower line denotes loss according to the table by Assmann/Franz (1963).

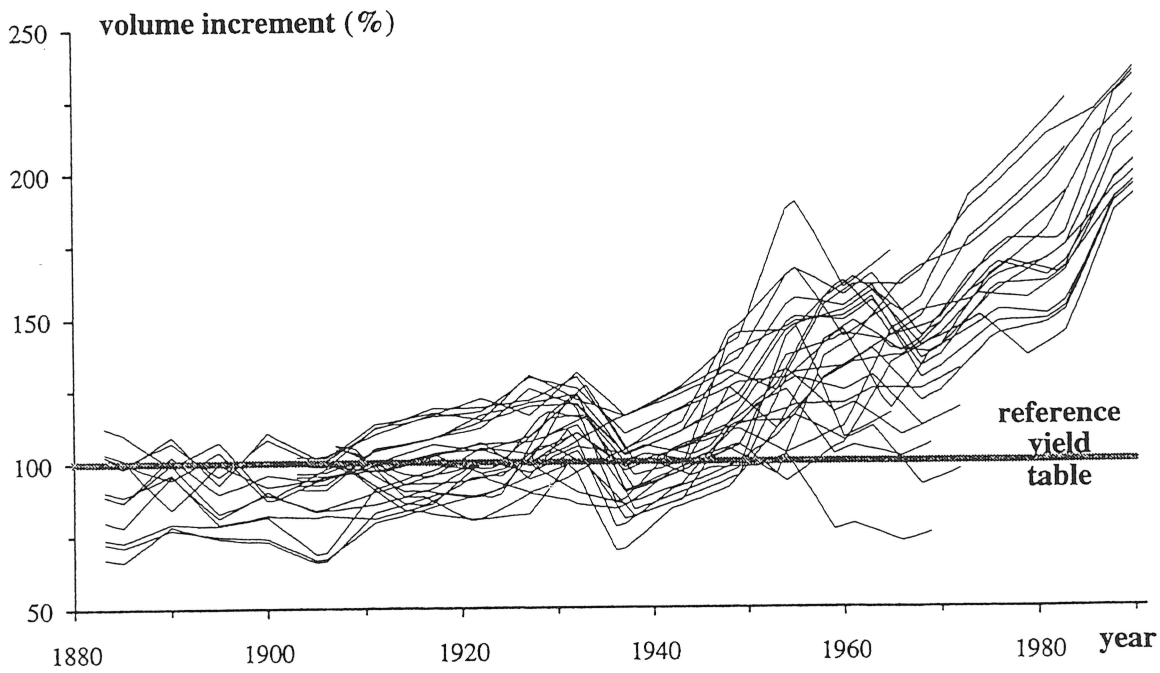


Fig. 7. Development of volume increment on 26 sample plots of the permanent experimental areas Denklingen, Eglharting, Ottobeuren and Sachsenried, compared to the yield table by Assmann/Franz (1963) over the calendar year (Röhle 1994).

used as reference. For over 30 years there has thus been a continually widening gap between actual growth behaviour and expected yield table values. So far no reversal in this development is discernible, i.e. there is no tendency towards a return to the increment level as set down in yield tables. Accordingly, absolute volume increments between 15 and 20 m^3 ha^{-1} y^{-1} are being recorded for stands between 120 and 130 years of age.

Growth conditions have improved considerably in the past decades as can be verified by comparing previous and successive stands. In the experimental areas network in Southern Bavaria there are a number of long-term plots where the second stand generation can now be observed on the same location. For example, the experimental area Sachsenried 03 was followed by the experimental area Sachsenried 602 on the same location (Fig. 8). Aged 29 years, the successive stand (with a top height of 14.5 m corresponding to yield class 39 by Assmann/Franz 1963) is obviously much taller than the previous stand with a top height of only 13.8 m at age 33. The superiority of successive stands is even more impressive with respect to volume development. Volume on experimental plot Sachsenried 602 reached solid timber amounts of 339 m^3 at age 29, while the previous generation on the experimental plot Sachsenried 03 achieved only 50% of this volume on the same location, i.e. 180 m^3 at age 33. These results correspond well to those gained by Kenk, Spiecker and Diener (1991). According to the latter investigations, also conducted on long-term trial plots in Baden-Württemberg, in particular on poorer sites, considerably better growth had been observed on successive stands than in preceding stands.

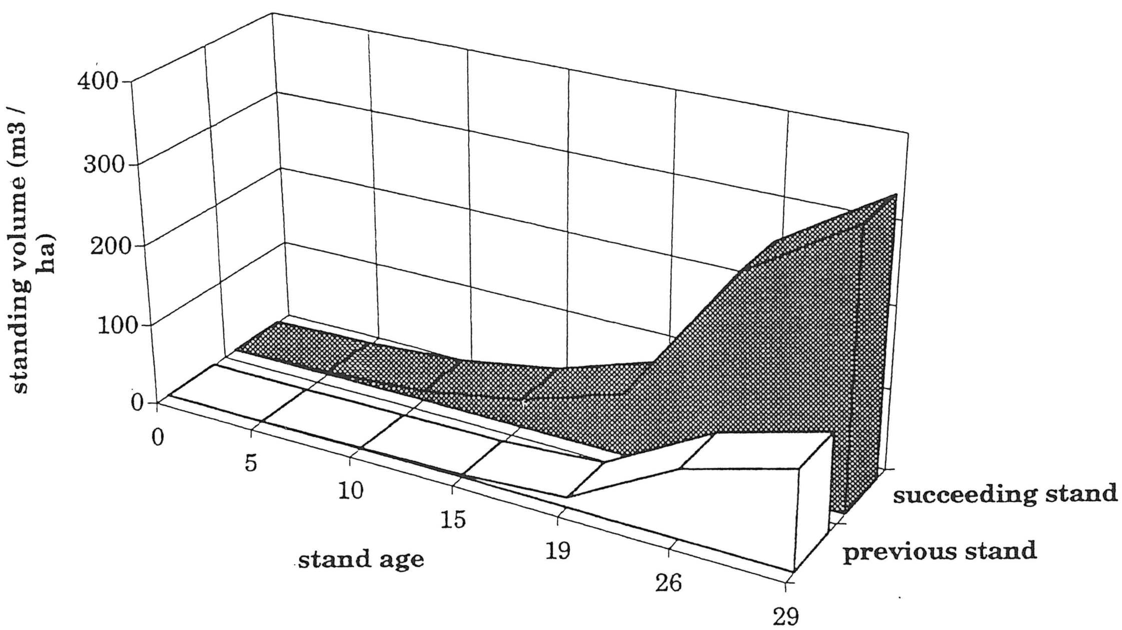


Fig. 8. Volume development of the previous and the successive stand of the long-term spruce experimental area Sachsenried 03/602 in Southern Bavaria (Röhle 1994).

2.3. Pine Stands

In pine stands, too, a significant growth increase was observed in the course of past decades (especially in originally poorer locations in the Upper Palatinate, Franconia and Brandenburg). One of the external signs is that long-shooted peaks between 3 and 5 m in height are seen to project from the round, vaulted, domed crowns of older pine stands (Pretzsch 1985) - a characteristic typical of dominant trees in middle-aged and older stands (Fig. 9). Figure 10 shows exemplary height growth developments on experimental areas in the forest district Schnaittenbach/Upper Palatinate, which accounts for a crown form rather atypical of the age of the trees presented in Fig. 9. The top height developments of the experimental pine stands which exhibit these symptoms are compared to height curves according to Franz (1983). Since the early 1960s, a significant yield class improvement (between 1 and 2 relative classes) can be found as regards height increment in all examined stands, independent of specific stand age. For the past two or three decades height increment development in the examined stands was no longer in line with trends described in the yield tables.

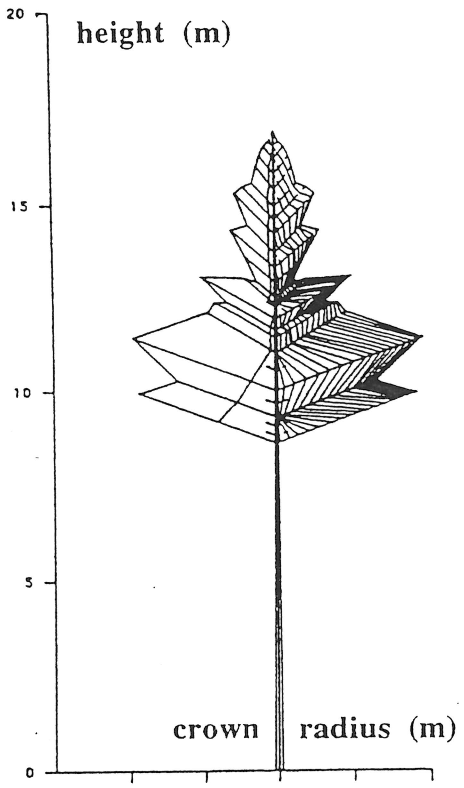


Fig. 9. Crown structure of a pine of the forest district Burglengenfeld/ Upper Palatinate (Pretzsch 1985).

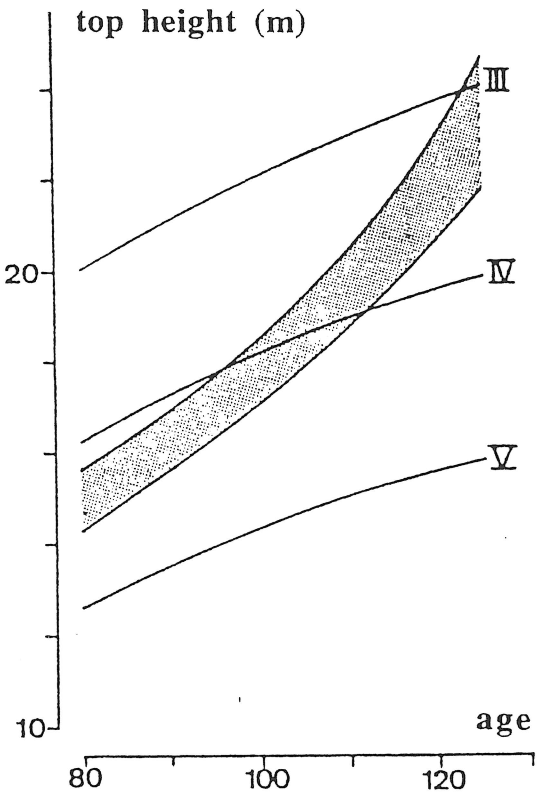


Fig. 10. Top height development on pine experimental plots near Schnaittenbach/Upper Palatinate compared to top height developments according to Franz (1983) for moderate thinning (Pretzsch 1987).

This development is also reflected in basal area increment curves (Fig. 11), which represent basal area increment on experimental pine stands in the Upper Palatinate, compared to the table by Wiedemann (1948) for moderate thinning from below (Pretzsch 1992a). Up to the 1960s, the curves of the annual basal area increment of these pines corresponded to expected yield table values. Since then, a significant improvement in increment level was observed in a great number of the pine stands under investigation. For two or three decades, basal area increment no longer coincided with expectation values of yield tables and reached levels of as much as 200 and 250% of yield table values according to Wiedemann, with a final level that even exceeds expected values for the period of increment culmination in the early years of the stand. These experimental plots demonstrate an increment increase that is absolutely contrary to the normal age trend, independent of stand age.

The causes of this significant growth increase in past decades may be assumed to be the following: increased nitrogen input, increase in carbon-dioxide concentration in the air, improved stand treatment (leading to yet more increment) and - on several locations - the cessation of litter raking (Hofmann et al. 1990; Klopries and Beckmann 1989; Thomasius 1991; Ulrich and Puhe 1992). Not always can a single dominant disruptive factor be found with an influence on increment behaviour as evident as in the case of pine stands in the East German lowlands as examined by Hofmann et al. (1990). The latter and other investigations reveal that both positive and negative increment reactions can follow upon one another as a result of nitrogen input. Nitrogen input, small doses of which can have an increment-promoting effect may, upon passing a saturation phase, initiate the destabilization and devastation of entire stands.

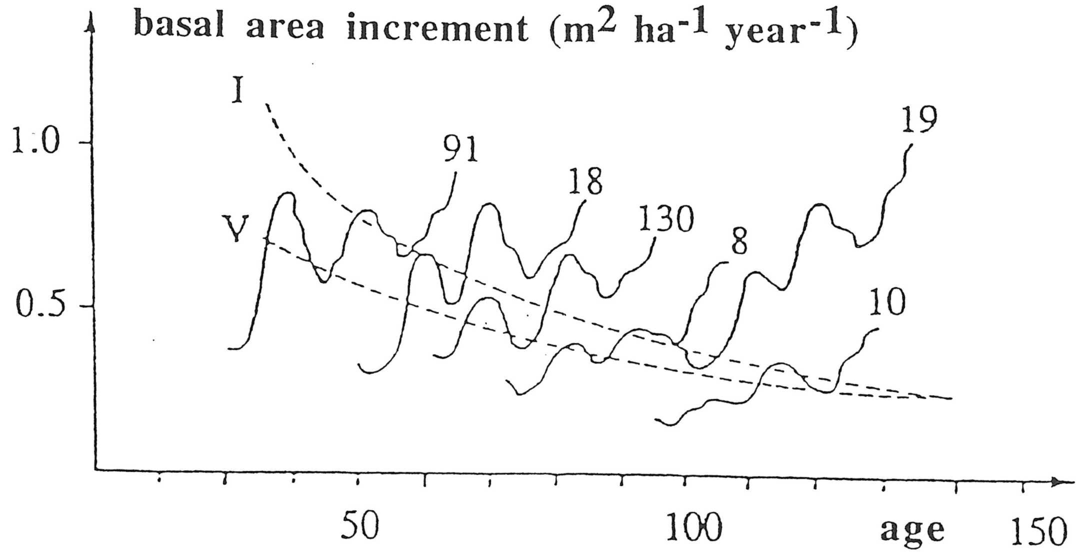


Fig. 11. Increase in annual basal area increment on indicator plots in pine stands of the Upper Palatinate compared to the yield table by Wiedemann (1948) for moderate thinning, yield classes I. and V. (Pretzsch 1992a).

2.4. Beech Stands

Growth trends on the long-term experimental plot Fabrikschleichach 015 in the forest district Eltmann in the Steigerwald show how far the actual growth behaviour of beeches may deviate from what one would expect. The experimental plot covers the treatment variants light, moderate and heavy thinning from below (A, B, and C degree). Figure 12 demonstrates the development of the periodic annual stand volume increment since the area was first assessed in 1870. This is compared with the expected increment values for yield classes I and III according to the yield table by Schober (1967) for moderate thinning. All three thinning variants show age devel-

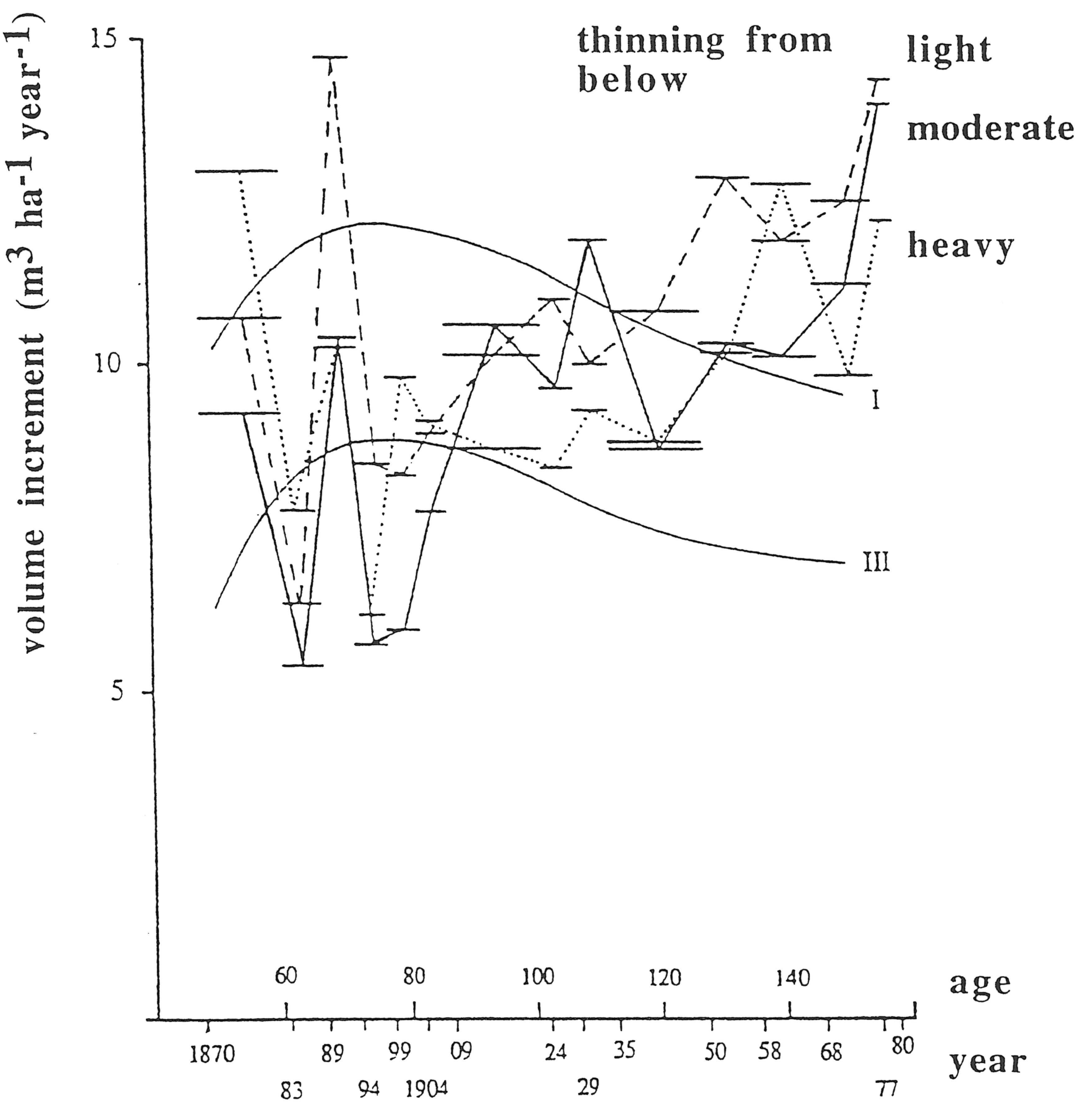


Fig. 12. Volume increment development on the beech thinning experimental area Fabrikschleichach 015 in the forest district Eltmann/Steigerwald. Comparatively, increment curves for the yield classes I. and III. according to Schober (1967) for moderate thinning are indicated (Pretzsch 1992a).

opments contrary to the typical age trend given in the table: in the first third of the observation period of over 120 years, increment trends covered the entire yield class range. In the following period, where, according to the yield table, increments were expected to decline, volume increments on all three areas rose considerably and have continued to do so to this day.

Following an initial peak at age 60 to 80, there was another one between ages 140 to 160 with values ranging from 12 to 14.5 m^3 ha^{-1} y^{-1} (under A, B and C degree conditions). Here, increment increase cannot be attributed to the fact that thinnings caused growth acceleration as it was also evident on the A-degree plot. The actual rise in increment amounts to 140 to 160% of expected yield table values. Similar trends (atypical of respective stand age) and deviations from table values were also observed on other experimental plots (Franz, Röhle and Meyer 1993; Foerster 1993).

2.5. Fir Stands

Similar growth behaviour was diagnosed for fir. As for spruce, pine and beech, fir shows increment decrease and decline in regions heavily damaged by immissions (Kenk 1984; Schöpfer and Hradetzky 1986); on the other hand, in other regions with pure and mixed fir stands there are positive deviations from the expected growth behaviour. Experimental area Wolfratshausen 97 in the forest district Starnberg is one of the rare pure stands of fir under long-term observation (Pretzsch 1992b). Based on its crown vitality, this stand is categorized as "moderately damaged". Nevertheless, in the past two to three decades the 140-year-old stand has achieved a considerable increment increase that is not typical for its age. As far as height increment is concerned, this A-degree area rates between yield classes II and III according to the fir yield table by Hausser (1956) for moderate thinning. As for standing volume development (Fig. 13, left) and volume increment (Fig. 13, right), this area has by far exceeded yield table values in the past two or three decades. Similar to spruce, pine and beech, increment increased in a manner that was atypical of the respective age during the 1960s and 1970s and has kept this up to the present day.

2.6. Oak Stands

For the species oak, severely damaged in some regions, there is every reason to assume that increment also increased in other regions. Such growth behaviour will be illustrated with the help of basal area developments on six plots of the oak thinning experiment Waldleiningen 88 in Rhineland-Palatinate (Fig. 14). Two of the six plots represent light thinnings, two moderate thinning, and two heavy thinning. The lightly thinned plots 2 and 5 obviously approached the maximum basal area typical of the respective location at age 80 to 90. Since then, the basal area has varied between 36 and 42 m^2. This high growth level accounts for the fact that even with moderate

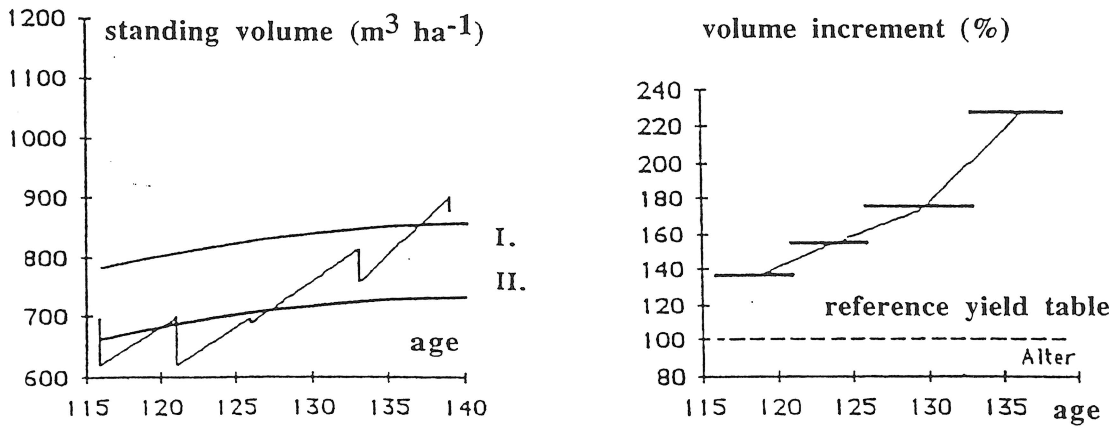


Fig. 13. Development of standing volume (left) and percent volume increment (right) on the fir experimental plot Wolfratshausen 97/1 compared to the yield table by Hausser (1956) for moderate thinning (Pretzsch 1992b). Comparatively, the volume increment for the yield classes I. and II. is indicated (left); volume increment is shown in relation to that of the yield table (right).

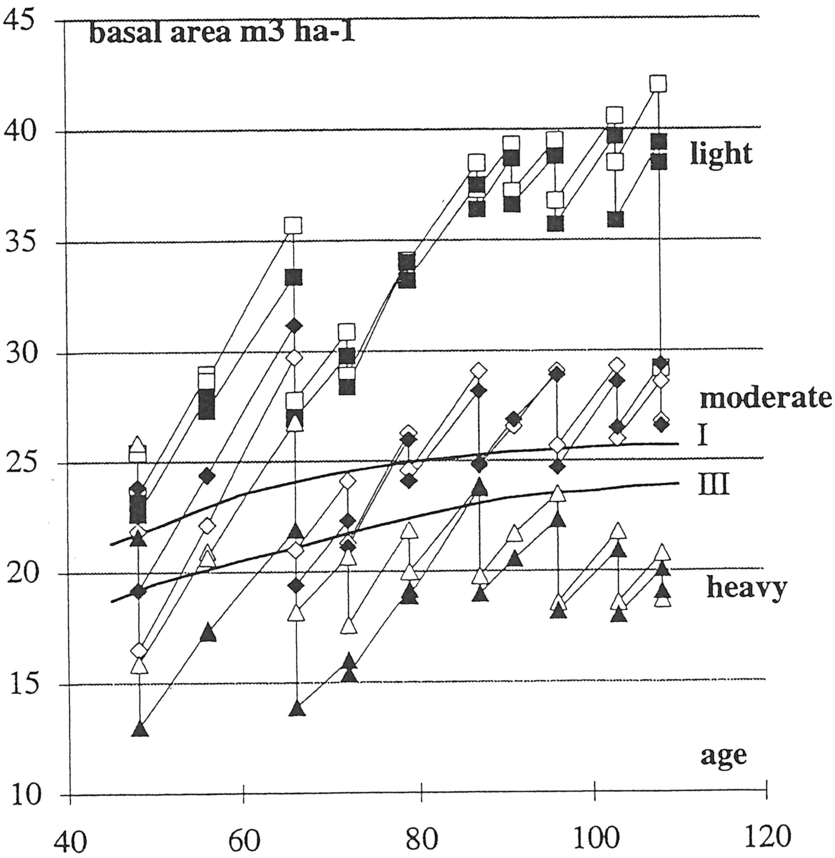


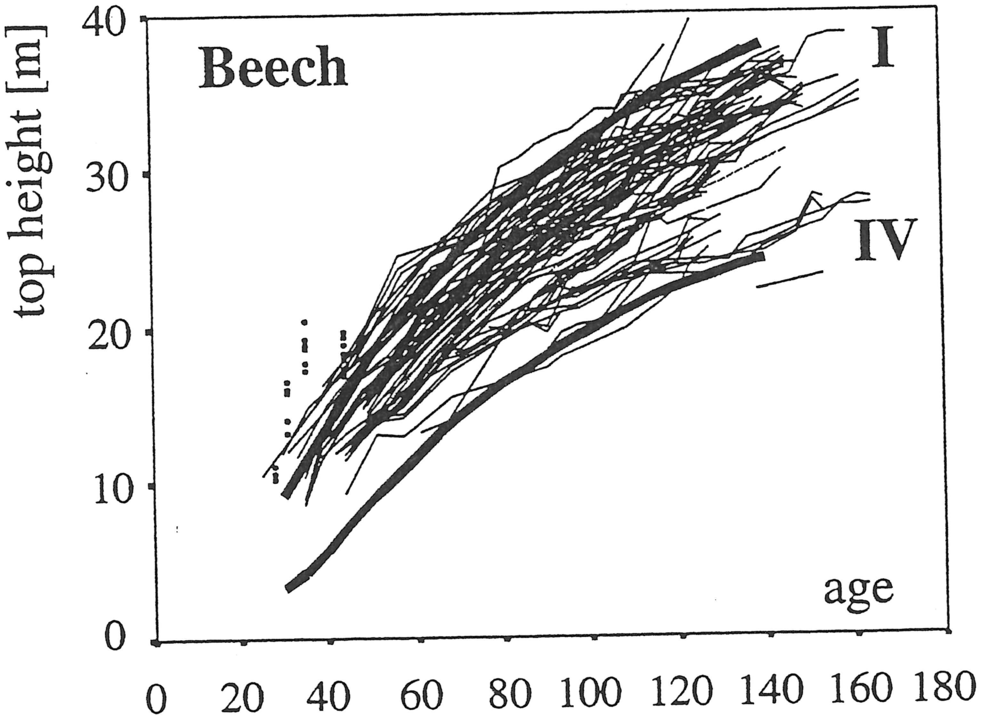
Fig. 14. Development of basal area on six plots of the oak thinning experiment Waldleiningen 88/Palatinate (light thinning, moderate thinning and heavy thinning) compared to the oak yield table by Jüttner (1955) for moderate thinning and yield classes I. and III. (Pretzsch and Utschig 1995).

or heavy thinning and a decrease of 30 and 50% respectively, in the referential basal area of the A-degree, basal area values at Waldleiningen temporarily surpass those of yield tables by Jüttner for moderate thinning. Both basal area and volume development are, except for the heavy thinning, considerably higher than given in the yield table according to Jüttner (1955) for moderate thinning and for yield classes I and III. Standing volume on experimental area 88 has increased to 600 m^3 ha^{-1} (A-degree) and development curves show no tendency to level off. As a result, volume at 108 years of age is the same as for veneer oak stands 300 years old and over. The expected level of standing volume is thus surpassed by 60%. Correspondingly, the level of total volume production is high and amounts to between 694.0 and 824.0 m^3 ha^{-1} on these experimental plots. High basal area and standing volume cast doubt on the suitability of conventional thinning concepts for oak. Neither the conventional numbers of selected trees nor conventional basal area concepts will be capable of exhausting the potential performance of the species oak at the described location. Preuhsler and Stögbauer (1990), Utschig et al. (1993) and Pretzsch and Utschig (1995) reported similar hypertrophic increment processes in oak stands. Again, this development was ascertained to have been sustained over the past two or three decades.

3. Site Class Development on Long-Term Experimental Plots in Germany

For a representative view of site class development of the main tree species in Germany (and to give a presentation of this development in relation to site conditions), Kahn (1994) compiled data on top height development of a considerable number of long-term experimental plots (some observed since 1860) of various German research stations and several university institutes. Figure 15 shows top height development of 47 plots in spruce stands, 89 plots in beech stands, 81 plots in pine and 37 plots in oak stands. This extensive data material for assessing height development is comparable to the outstanding Wiedemann evaluations made in the 1930s and 1940s. The experimental plots cover a wide range of locations: north-south extension between Schleswig-Holstein and Switzerland; east-west dimension between the Bavarian Forest and the Rhineland/Palatinate; height classes ranging from "better than I" to "worse than IV". Figure 15 provides information on the top height development of the world's oldest experimental area network.

The following basic statements about the site class development in Germany can be deduced from the four graphs (Fig. 15): first, a considerable number of the experimental plots is above the yield class I of respective yield tables (as far as height growth is concerned). The older the stands, the more numerous the positive deviations from the yield tables. Second, positive deviations prevail at all age levels, whereas there is practically no decrease in height development in relation to yield



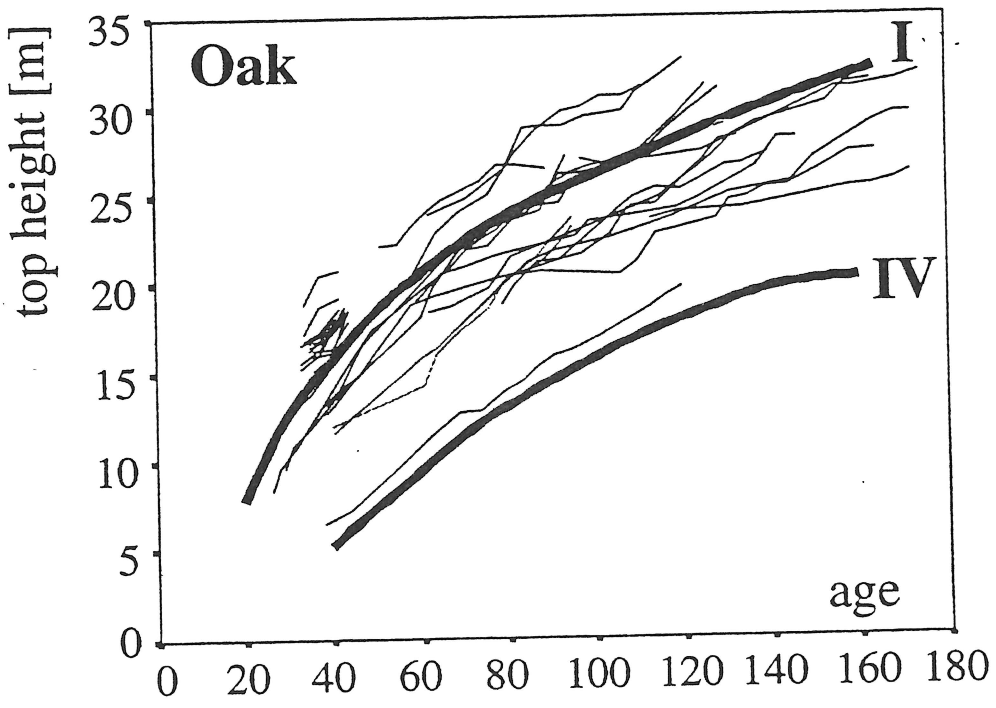


Fig. 15. Top height growth development on the long-term experimental plots for spruce, beech, pine and oak in Germany and Switzerland (according to Kahn 1994). Comparatively, the height curves for spruce, beech, pine and oak according to Wiedemann (1936/42), Schober (1967), Wiedemann (1943) and Jüttner (1955), each for moderate thinning, are indicated.

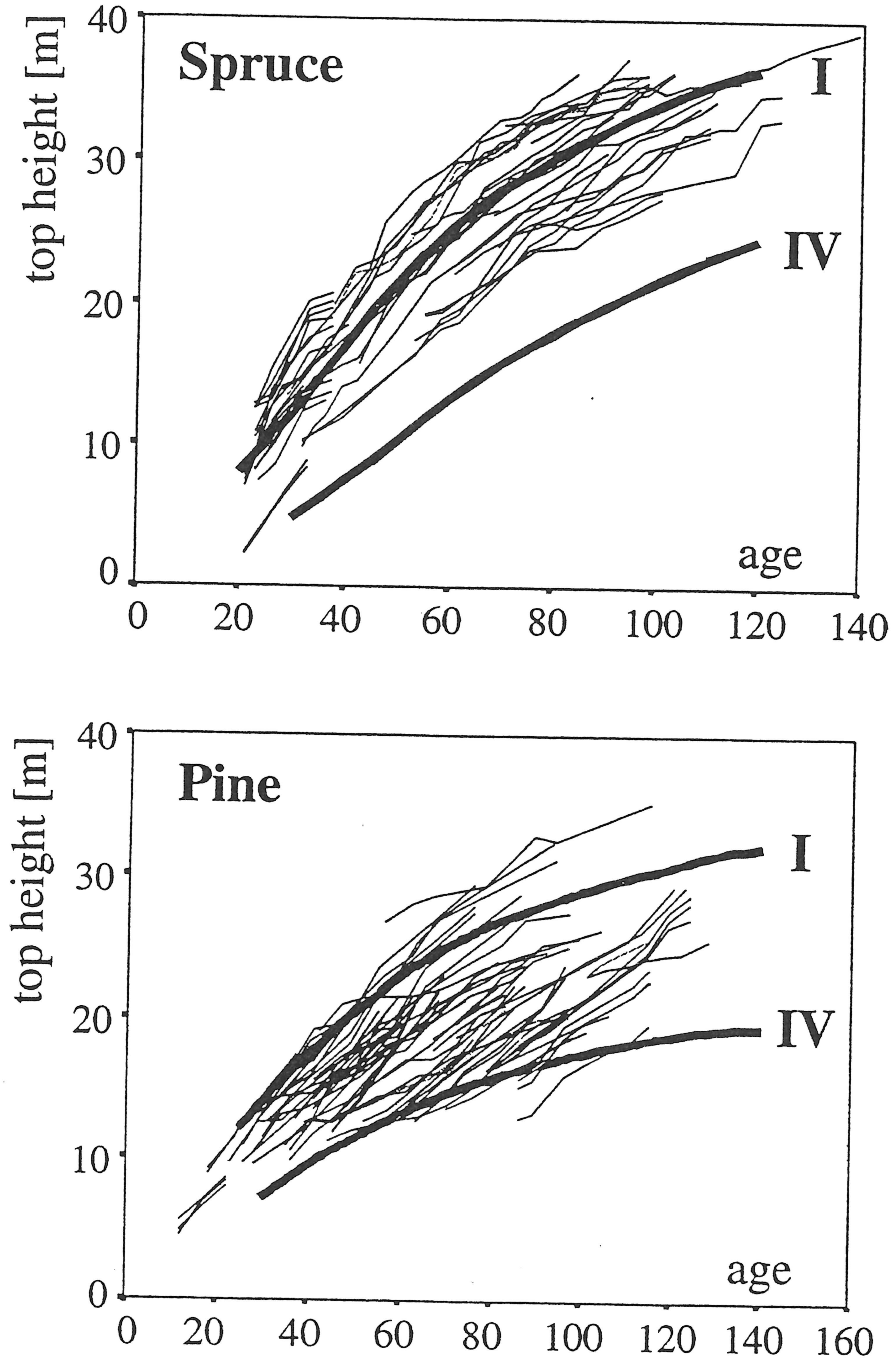


Fig. 15. Continued

tables. Third, young crops of oak and beech by far surpass expectation values of the yield table. Fourth, positive trend deviations and superiority to yield tables are most remarkable for pines, which mainly grow on poorer locations.

Changes in height growth level as well as described deviations from yield tables are by no means of marginal importance but represent a fundamental change in growth conditions, as compared to those assumed in the yield tables. Such changes in growth conditions must be taken into account whenever yield tables are used in forest management. Moreover, these changes can have important consequences for the care of pure and mixed stands. A change in height increment and height growth development has a decisive impact on the competitive behaviour between tree species and calls for the transition to adequate thinning regimes in the control and regulation of mixed stands.

4. Growth Development of the Main Tree Species According to the Results of Repeated Inventories

Reliable information is available on yield class and increment developments of the main tree species in Bavaria in the course of the past 20 years. Bavaria is the most densely wooded part of Germany (over 2.5 million hectares of woodland). It is the only federal state in Germany where two successive forest inventories with comparable inventory sampling methods were carried out. The first extensive inventory was made in 1971, and another in the years 1986-1990 (fixed day 10/1/1987) when Bavarian woodlands were assessed in the course of the Federal Forest Inventory; 17 vegetation periods have passed between these two inventories, a period long enough to permit reliable conclusions to be drawn on yield classes and increment development (Foerster, Böswald and Kennel 1993; Foerster and Böswald 1995).

4.1. Development of the Height Yield Classes

Figure 16 illustrates yield class results over age classes for the first inventory in 1971 (solid line) and the Federal Forest Inventory in 1987 (broken line). Yield class data of the tree species spruce, pine, beech and oak is based on yield tables by Wiedemann (1936/42), Wiedemann (1943/48), Wiedemann(1932) and Jüttner (1955), each for moderate thinning. A close look at the yield class data of the two inventories in dependence on age class, and at yield class development between the first and second inventory reveals that similar trends exist for the four main tree species (spruce, pine, beech and oak). First, all species show a remarkable decrease in yield class with advancing age. This development may perhaps be attributed to better growth conditions of young crops growing at the present time (due to more careful forest treatment methods and a more favourable nutrient situation, e.g. nitrogen in-

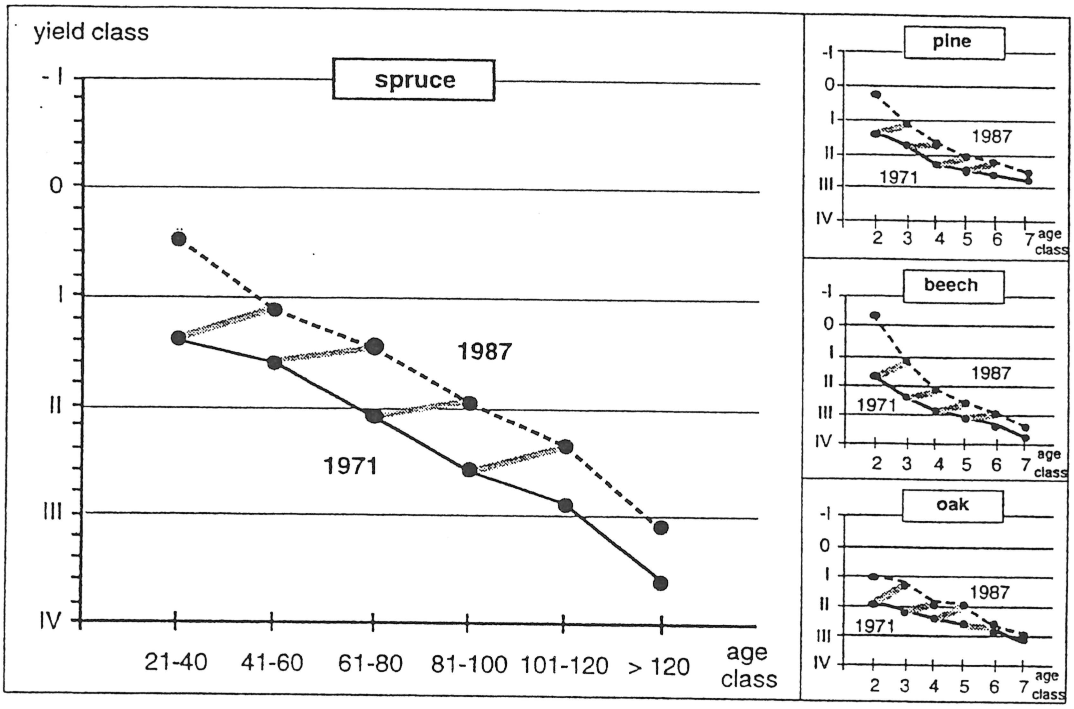


Fig. 16. Yield class development of Bavarian spruce, pine, beech and oak stands for the period covering the Bavarian inventory 1970/71 (solid line) to the Federal Forest Inventory 1986-1990 (dotted line) according to Foerster and Böswald (1995). The yield class changes of the different age classes of spruce, pine, beech and oak refer to the yield tables by Wiedemann (1936/42), Wiedemann (1943/48), Wiedemann (1932) and Jüttner (1955), each for moderate thinning.

puts) compared to the situation of old stands. Second, yield classes improved considerably in the course of the observation period of 17 years. As expected, this improvement is more clearly manifest in young crops than in old ones. The fact that this yield class increase took place within the short time of 17 vegetation periods gives an idea of the extent of the divergence between expected and actual growth development of our main tree species. This improvement indicates that stand development is not in agreement with developments to be expected from yield tables.

It can be deduced from the figures that there is a higher yield class increase when considering the change within individual age classes rather than the shift between age classes. The yield class of spruce in the first age class (age 21 to 40) was improved by almost one relative site class (from I.5 to 0.5) between 1971 and 1987. A comparison of identical stands and site class shifts in the period between the first and second inventory shows a slightly smaller increase in yield class increase (grey arrows). This implies that there may be a combination of the two following effects: first, young crops are generally established on more favourable sites. Second, modern thinning regimes, nitrogen inputs, less litter raking etc. all contribute towards improving site conditions of existing stands.

4.2. Standing Volume and Volume Increment

Based on the volume situation recorded in the first inventory in 1971, the second inventory in 1987 and yield data during this period (including a roughly calculated loss of 15%), calculations can be made for the increment in the period between 1971 and 1987 and offset against respective growth level of yield tables. Table 1 provides the following information on volume and increment development in the observation period: In 1971 the standing volume per hectare of the main tree species lay between 232 and 344 m^3 and had risen to between 263 and 415 m^3 by 1987. The average periodic increment for spruce, pine, beech and oak of 12.6, 8.5, 6.4 and 5.7 m^3 ha^{-1} and annum respectively were by no means absorbed by felling quantities. If real increment is compared with yield table increment, a real increase is apparent of between 10 and 40% above expectation values of the yield tables. If forest practice adheres to the thinning regimes and quantities of yield tables the logical consequence will be an even greater volume accumulation. Overstocking is responsible for a decrease in stability and a decline in increment (Assmann 1961). The deviations established in Table 1 between expected and real increment behaviour yet again underline the necessity to elaborate new growth models which are sensitive to local site conditions, i.e. growth models are required that are more easily adaptable to respective growth conditions than is the case with yield tables.

Table 1. Standing volume and increment development of the species groups spruce, pine, beech and oak according to the results of the Bavarian inventory 1970/71 and the Federal Forest Inventory between 1986 and 1990 (Foerster and Böswald 1995). The percental increments for spruce, pine, beech and oak refer to the yield tables by Wiedemann (1936/42), Wiedemann (1943/48), Wiedemann (1932) and Jüttner (1955), each for moderate thinning.

Growth and yield data 1971 - 1987 for Bavaria	spruce/ fir	pine/ larch	beech/other broadleaves	oak*
standing volume 1971, (m^3 ha^{-1})	344	240	232	233
standing volume 1987, (m^3 ha^{-1})	415	275	271	263
volume rise 1971 - 1987, (m^3 ha^{-1})	+ 72	+ 35	+ 39	+ 30
regular yield 1971 - 1987, (m^3 ha^{-1})	123	95	61	58
other losses, (m^3 ha^{-1})	18	14	9	9
total volume growth 1971 - 1987, (m^3 ha^{-1})	214	144	109	97
mean annual growth 1971 - 1987, (m^3 ha^{-1} y^{-1})	12.6	8.5	6.4	5.7
yield table prognosis 1971 - 1987, (m^3 ha^{-1} y^{-1})	9.6	5.9	5.7	4.5
real growth versus yield table growth, (%)	+ 31	+ 43	+ 12	+ 27

*While the data for spruce, pine and beech refer to the Bavarian State Forest, growth and yield information for oak reflects the situation in the entire Bavarian forest region. Reference to the whole Bavarian forest area provides more solid estimation values for oak.

5. Conclusions

5.1. Conclusions for Forest Practice

With the comparison of damage classes, yield tables, previous and successive stands, a number of different methods for the diagnosis of increment trends was used, whose advantages and deficiencies were discussed by the German Association of Forest Research Stations (DVFFA 1988). Information on discrepancies between yield tables and reality are of the greatest importance to practical forest management planning, which continues to rely largely on yield tables. Hence the comparison with yield tables was used as a reference for all observed tree species. The various reference methods led to the following well-correlated results: forest growth, interpreted rather statically in the past, is a reflection, to a much greater extent than hitherto supposed, of dynamically changing environmental conditions. Environmental conditions such as air pollution, frost and draught cause growth reductions which are superimposed by effects of rising carbon dioxide concentrations and nitrogen inputs. Both act as growth boosters, so that a decline in growth below the level of yield tables is merely observed at higher elevations in the German Middle Mountains in stands subjected to severe air pollution. Increment depression in these locations versus increment increase elsewhere: up to the present time the main point of interest has been the actual development and very little has been done other than to collate symptoms and possible underlying causes. However, there is good reason to suppose that this is not merely a period where growth trends are temporarily thrown out of gear, at the end of which conditions will return to normal and conventional prognostic models can once again be applied. Global changes in productive conditions seem to be becoming the norm whereas growth conditions that were hitherto assumed to be static will become the exception (Thomasius 1991; Ulrich and Puhe 1992). However, despite ambiguous production conditions and uncertain overall conditions, planning, realization and control in forest practice must continue. Economic decisions have to be taken even if there is a lack of detailed knowledge about ecological frame conditions. In damaged stands struck by increment depressions and mortality, economic measures must be aligned primarily to maintain these stands, e.g. by fertilizing and thinning operations to stabilize the stand, advance planting and pest control. If there is further decline and devastation of the stand, new plantations will have to be established as promptly as possible. Numerous studies deal with forest stabilization and the reafforestation in damaged regions. The consequences which should result from the diagnosed increment increase have not been taken into proper consideration. As regards increased increment rates the following silvicultural alternatives are recommended, some of which have already been put into practice: intensification of thinnings, prolongation of rotation periods especially under poor site conditions, transition to more intensive cultivation and to higher numbers of selected trees, and the establishment of mixed stand structures that take into account the changes in growth rhythms and the competitiveness of the respective tree species.

5.2. Conclusions for Future Growth and Yield Models

The present situation can be described as follows: it has been recognized that growth developments in our forests in many respects deviate from yield tables and model approaches. The point has not yet been reached where our deficient working basis can be replaced by a better and more adequate information system. However, a new model prototype has successfully been developed with whose help the kind of information and prognostic system can be outlined that will be required in the future under the changing growth conditions mentioned above. The first, essential frame condition for the establishment of a new model generation consists in the use of prognostic models that are capable of responding to changing climate and site conditions. Growth conditions can no longer be assumed to remain static. Second, the formation and intensive care of mixed stands has become an important factor in forest practice. Up to the present, we have had no suitable model approaches for mixed species stands (Franz 1987). Third, subsequent to the transition to modern thinning programmes that are mainly quality- and stability-oriented, the need for information has undergone a basic change, i.e. from mean and summation values for stands to detailed information on the growth of single trees under varying thinning conditions.

In response to these trends, the position-dependent stem simulator SILVA 1 was developed in recent years (Pretzsch 1992c). It is capable of modelling the growth of single stems in pure and mixed forest stands of all age classes. The current static management model SILVA 1 will be combined with water and nutrient supply models and a radiation model. In the present version of the model, increment prognosis for the single tree assumes a potential increment related to respective site conditions. Potential increment is reduced to real increment by competition indices (determined geometrically) that describe the competitive situation of the single tree. In the future model, SILVA 2, single tree development will be controlled in a more causal way: the increment potential can be estimated in dependence on the water and nutrient supply, as competitive conditions are basically the result of nutrient and water supply as well as of the light regime. Increment reductions are also specific to site and climate conditions. SILVA 2 will be a planning and research instrument, calibrated mainly on the basis of empirical data material obtained in the course of long-term observations of increment developments. These new quasi-causal approaches have, of course, some weak points (e.g. in the determination of the interactions between climatic, nutrient and treatment effects). Nevertheless, they will be the only reasonable alternative to conventional yield tables in the near future. It is only with the help of new site- and climate-sensitive models that quantitative estimations of increment reactions will be possible, even under conditions of global changes and their impact on site conditions and growth trends.

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