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American Association for the Advancement of Science
1992


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Biomass and Carbon Budget of European Forests, 1971 to 1990

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In severely polluted areas, such as locally in Montshegorsk in northwestern Russia, all trees have died. However, measurements from Austria, Finland, France, Germany, Sweden, and Switzerland show a general increase of forest resources. The fertilization effects of pollutants override the adverse effects at least for the time being. Biomass was built up in the 1970s and 1980s in European forests. If there has been similar development in other continents, biomass accumulation in nontropical forests can account for a large proportion of the estimated mismatch between sinks and sources of atmospheric carbon dioxide.

Forests involve a larger variety of economic, cultural, and social dimensions than perhaps any other natural resource. Forests can be used for industrial and energy production purposes. In addition, they are part of the landscape accessible to people. Forest-dependent fauna and flora represent an enormous heritage of biodiversity. Forests, in comparison to, say, oil reserves, are widely distributed among countries, different regions, owners, and owner groups. Non-owners enjoy environmental benefits from forests and affect management practices by means of publicity and the democratic process. These special characteristics of forests have stimulated discussion and debate on the resource. The discussion in Europe in the 1980s largely focused on one issue, that of the impact of air pollutants on forests.

Air pollutants affect forest ecosystems in many ways. Surveys in Finland, for instance, revealed a decline of epiphytic lichen species over an area of more than 100,000 km² during the past 25 years (1). Trees themselves rely on nutrition from deeper soil layers and are less susceptible than the sensitive lichen species to air pollution damage but, as seen in severe cases of decline, trees have their tolerance limits.

Research programs in both North America and Europe have addressed the impacts of air pollutants on ecosystems (2), and forest surveys and growth investigations have been carried out for a long time. Results from all the different studies form an important basis for judgments about the past and future development of forest resources. We analyze and discuss various research results, realizing that any statistical presentation is bound to oversimplify and distort the extreme diversity of what is called "European forest" (3). We focus on the growing stock and growth...
of European forests. The objective is to contribute to the description and understanding of the development of forest resources and forest biomass in the 1970s and 1980s. Reference is made to the impacts of sulfur and nitrogen deposition on forests and to the contribution of European forests to the global carbon budget.

Development of Forest Resources

Growing stock. Growing stock, the stem volume of living trees, is an important indicator variable of forest resources. We are interested in the average growing stock over large forest regions, preferably over the entire country. The best method of providing objective information on forest resources is to take ground measurements from sample plots located randomly or in a systematic grid. The expression "forest resource survey" is used to refer to assessments that are based on statistically representative ground measurements. Additional information based on other methods such as remote sensing, measurements from subjectively located plots, or expert judgment, is useful. However, it cannot replace systematic ground measurements in estimating the true magnitude of forest resources at any given time.

During the past two decades, reports of forest resource surveys have been available from Austria, Finland, France, and Sweden (5). In addition, assessments can be made for the former West Germany and for Switzerland, although earlier surveys in these cases were not based on systematic sampling in the strict sense (6). Growing stock in these countries has increased (Fig. 1). The most rapid increase was reported in Germany, but this might reflect an underestimation of the baseline resource of 1961.

Countries that do not carry out forest resource surveys assess growing stock mainly by combining management plan inventories. They are based on standwise ocular estimates. The United Nations Economic Commission for Europe (ECE) has collected information from all European countries and has also published national projections of growing stock up to 2020 (3). All countries reported an increase of growing stock between 1950 and 1980. According to these statistics, growing stock increased in Europe by 12.3% between 1971 and 1980. The increase was projected to continue at a reduced rate (Fig. 2). However, the countries that have carried out forest resource surveys since 1980 did not report a slackening of the trend (Fig. 1). Therefore, we estimate an unchanged development in the 1980s, yielding a 25% larger growing stock in 1990 than in 1971.

Forest growth. The increment of stemwood volume (forest growth) is another important indicator of forest resources. Like growing stock it can be measured from forest resource surveys. The technique is slightly more demanding, including remeasurement of permanent sample trees or tree ring analysis of systematically chosen trees. Growth measurements are available only from a few forest resource surveys. The observed trends were similar in Finland, France, and Sweden, indicating that forest growth increased by about 30% between the early 1970s and the late 1980s (Fig. 3).

Decline cases. Investigations on severe forest decline are under way, for example, in the vicinity of Monshegorsk smelter, Kola, in northwestern Russia (7). The smelter is located north of the Arctic Circle, yet within a forested landscape about 100 km south of the Arctic timberline. After establishment of the plant in 1939, the sulfur emissions increased to annual amounts of about 110,000 tons in the 1980s. The emissions contain heavy metals. The area of forest decline surrounding this plant is perhaps the largest in Europe around an individual point source at the present time. Within a radius of 5 km only dead trees are available for increment sampling and retrospective growth analyses.

Severe decline like that at Monshegorsk is rare. On the basis of country reports to the ECE programs, remote sensing, national surveys, field investigations, and expert reports, we estimate that an upper approximation of the area of severely damaged forests would be 2000 km² in the former Soviet Union, 1000 km² in Poland, 1000 km² in Czechoslovakia, and 1000 km² in Germany and that in the rest of Europe, less than 3000 km². Thus, based on this first approximation, cases of severe decline in Europe cover a maximum of 8000 km², or less than 0.5% of the forest area, and so do not have much impact on the forest resources of the continent.

Growth at tree and stand level. Tree growth has been studied in many European countries and in many tree species. The investigations have generally indicated a slight increase of tree growth during this century (8). In Germany, present stands were observed to grow faster than the stands of earlier rotations on the same plots. Favorable climate conditions (high temperatures and high precipitation) and the increasing effect of nitrogen deposition have been mentioned as possible causes of this increase (9).

In southern Sweden, Hallbäcken and
Tamm observed soil acidification in terms of declining pH between the 1920s and the 1980s (10). In another study from the same region, stored soil chemistry samples from 29 stands, taken in the 1940s, were compared with recent samples from the same sites (11). Acidification was observed as pH decline and as a decrease in the levels of sodium, manganese, zinc, calcium, magnesium, and potassium. There was a simultaneous increase in nitrogen availability. Compared to the appropriate reference level, the growth of beech stands increased, yet the growth of oak stands remained stable. The interpretation was that fertilization responses obscured the potential adverse effects of soil acidification.

The Concept of Forest Decline

The facts about forest resources seemingly contradict the widely held view that European forests are declining. It is important, however, to understand the different objectives and dimensions of forest assessments. It is also important to take a look into the future, as well as into the past. We first elaborate on reasons for the increase of forest resources and then describe pitfalls in the interpretation of forest health surveys, which have contributed to pessimistic views about European forests.

Trends in land use. Afforestation of surplus fields and pastures and the drainage of peatlands, especially in the Nordic countries, increased the area of exploitable closed forests in Europe by 2.5% between 1970 and 1980 (3). Initially, afforested land is covered by seedlings. Growing stock and stand growth remain low during the early phases of a rotation. The increase of growing stock and forest growth observed in Europe between 1971 and 1990 is almost entirely from stands that were already in place in 1971.

Unexploitable closed forest in Europe occupies about 140,000 km² or nearly 7% of total forest and other wooded land (3). An area is classified as unexploitable closed forest as a result of criteria such as physical inaccessibility; legal restriction of commercial felling because of protection, conservation, or biological or recreation functions; and economic criteria (low stand productivity or excessive costs of harvesting or transport). The buildup of wood in unexploitable forests makes only a minor contribution to the observed trends of increase in standing stock and growth.

Universal-global tendencies. Clawson reports that growing stock and timber growth potential in the United States have been "repeatedly and seriously underestimated" (12). An increase of forest resources can be explained by factors such as silvicultural development, favorable climatic conditions, the fertilization effect of additional nitrogen per square meter and from 0.5 to 2 g of sulfur per square meter annually (Fig. 4). Typical amounts of anthropogenic deposition in European forests vary from 1 to 4 g of sulfur per square meter and from 0.5 to 2 g of nitrogen per square meter annually (Fig. 4).

Negative and positive effects. The different, overlapping, and partly opposite effects of pollutants on forests can be analyzed in the same way as the effects of the variation of
natural environmental factors. Cannell (21) reviews the physiology of wood production and describes pathways for the effects of environmental factors on growth. It is a common perception that air pollutants have either negligible or adverse effects on such plant mechanisms. However, pollutants, like other environmental factors, can have both negative and positive effects on wood production, depending on conditions.

There is convincing evidence that the deposition of sulfur, nitrate, and ammonium has significantly modified plant nutrition and soil chemistry. Moreover, trees have responded to soil chemistry in terms of discoloration symptoms (22). In the long term, these processes can have adverse effects on forest resources.

It is possible, however, that fertilization responses, in particular to nitrogen, play a dominating role in a major part of the European forest area at the present time. A comparison can be made with the effect of applied nitrogen fertilizer. Even in Germany, where nitrogen deposition has been as high as 3 to 5 g per square meter per year, nitrogen fertilizer application has increased stand growth (23). In Finland it has been calculated that the nitrogen fertilization programs (24) contributed 1 to 2 million cubic meters per year to the growth of Finnish forests in the 1970s and 1980s (25). This is roughly 2% of the total stemwood growth, which was about 80 million cubic meters per year in 1985 to 1990. Growth responds less to deposition nitrogen than to fertilizer nitrogen. Deposition falls onto forest clearings and sparsely stocked areas, not just onto the most responsive stands. Di:position in winter can decrease much of the nitrogen that falls onto forest clearings and sparsely stocked areas, not just onto the most responsive stands. Di:position in winter can decrease much of the nitrogen that...
species, and contributed to the discoloration and defoliation of trees. Attention should be paid to such early warning signs, bearing in mind the irretrievable value of forest growth potential. Past development, nonetheless, guarantees that during the next 10 to 20 years, wood resources are plentiful and can be allocated among traditional forest industries, eventual novel technologies such as ethanol production (31), and nature protection and conservation purposes.

REFERENCES AND NOTES


6. In Germany, according to Agrarbericht 1991 (Deutscher Bundestag, Bonn, 1991) the growing stock per unit land area was about 160 m3 ha−1 in 1961 and 300 m3 ha−1 in 1987. The forest land area in 1987 was 77,500 km². We assume the same figure for 1961, in Switzerland, Schweizerisches Landesforstinventar, Ergebnisse der Erstaufnahme 1962–1986 (Birmensdorf, Switzerland, 1988).


15. European Community Forest Health Report 1989 (Commission of the European Communities, Di-