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MONITORING AND ASSESSMENT OF FOREST DAMAGE IN REGIONAL AND NATIONAL SCALE

Contribution to the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects in Forests

1. Abstract

Methods of forest damage assessment, applied in various countries, are being harmonized under the auspices of the Convention for Long Range Air Pollutants and the ECE/FAO Timber Committee. There is considerable need for such harmonization as the methods for the time being are quite diverse. It is useful as the first step to learn to understand why the methods are so different. The reasons may be related to the objective of the study, to the availability of resources and/or expertise, to the spatial and/or temporal scale of the assessment and to the quantity of air pollution observed in the respective forest area etc. Such possible reasons are often interrelated.

It is suggested that a binding agreement should be made on a requirement to locate the plots systematically or at random in such a way that regional assessments are valid and the accuracy of the results can be quantified. Freedom should remain for choices concerning the practical realization of such sampling principles. A small number of critical variables should be defined as obligatory variables. Regarding these variables, efficient standardization of

measurement should be organized between countries in order to find a basis for intercomparisons. Freedom should be given to national programs to measure additional variables.

For 1986 and largely for 1987 most countries have already taken decisions which restrict the harmonization of methods in such a short term. Build-up of new professional personnel takes time up to 2 to 5 years. It is obvious that the harmonization of damage assessment should be viewed as a continuous process with a time horizon of, say, ten years.

Data analysis and the presentation of results should be made comparable. An example is shown using Finnish data in order to indicate some procedures for extracting information from the data measurements. The conclusion is drawn that monitoring and survey should be organized in such a way that flexibility is quaranteed in data analysis.

2. Survey objectives

In 1980's, many European countries have conducted large scale surveys and assessments of the extent of forest damage. Air pollution damage has been the issue of largest concern. These assessments, however, appear as the first nation-wide systematic investigations of forest damage in general.

Statistical methods and sampling techniques can largely be deduced from those applied in forest resource inventories. Having been started in 1910's in Norway and developed continuously ever since by professional organizations in many countries, forest resource inventories have accumulated a rich scientific tradition of sampling optimization and data analysis.

The first objective of a forest damage survey is to obtain unbiassed estimates of the selected damage variables from all forests in a given country and, analogously, from circa 5 to 50 subregions of the country, subdivision depending on a number of factors.

The second objective is to obtain unbiassed time series of damage development. This is a very demanding goal because the data should be unbiassed both in time and in space. The measurements taken in a particular year should represent the whole forest area in such a way that the accuracy of estimates can be quantified. Moreover, the measurements taken in subsequent years should be consistent.

The third objective is to analyse the relationship between forest damage and air pollution load. Basis for this analysis can be obtained in several ways. Firstly, one can try to identify damage variables that are specific as such to a given type of air pollution. Secondly, one may set up integrated measurements in a forest stand that is, measure specific or non-specific damage variables and relate the results to pollution variables measured at the same site. Thirdly one can measure damage variables and pollution variables using independent observation networks, overlay the regional patterns and time series, and in this way analyse the relationships.

3. National characteristics

The average concentration and deposition of sulphur in Europe vary from one forest region to another by a factor of approximately 30 (Fig 1). Similar data is not available for other pollutants but, theoretically, only air pollutants with very long retention times in the atmosphere will appear in uniform quantities in all forests in Europe. Carbon dioxide (CO_2) is one of the few examples of "pollutants" of this type. It is obvious that air pollution is a large problem in some forest regions and a much smaller problem in some other regions.

Forest area in the European USSR is larger than that in FRG by a factor of ca 40. In Holland there are appr. 25 taxpayers per hectare of forest land as opposed to the not more than 0.13 in Finland: a difference by a factor of 180. Such differences have a great influence on the culture of forestry and upon the resources available for studying certain forest regions.

A single uniform guide of instructions for the forest damage survey in all European countries would be a rather unrealistic goal. It would necessarily imply that the resources are used in an inefficient way. By no means does this undermine grounds for the harmonization of methods. A strategy is proposed in the following that strict standards are introduced for locating sample plots either systematically or at random, and for selecting the sample trees at the plot in a statistically stringent way. Such a statistically relevant sample design would provide a basis for regional damage estimates and for the quantification of the accuracy of these estimates. Details of the method, such as the grid size, plot size, number of sample trees etc. could be decided at national level. Strict uniform standards are also proposed for a small number of key variables. A tentative list of such key variables is presented (Appendix). National studies are invited to take measurements on additional variables which later could be introduced as European key variables.

4. Establishing and developing a national study

41. Sampling intensity and damage variables

Sampling intensity in a national study depends on the severity of the air pollution problem, on the size of the forest area, the terrain and road network, and on the resources available for the inventory. Sampling would have to cover all forest land including forest edges. Sampling intensity might vary even within a country if only an unbiassed, predetermined statistical method is applied. Sampling method must be selected based on the information regarding the range of variation of the forest variables. Spatial and temporal variation determine the "noise" and the desired information determine the "signal". The signal-to-noise ratio can be used as a guide for the sampling intensity. It is cost-effective to use a dense grid in polluted regions and a sparce grid in less polluted regions.

Prior to any decision about sampling intensity, basic agreement should be achieved regarding the key variables. Crown density has been used in many countries as a basic variable. It has been critisized because

i) it is difficult to define a "reference tree",
ii) determining crown density is based on a visual and notably, on a somewhat subjective measurement,

iii) crown density is a non-specific variable that is, it is not dependent on air pollution only, and

iv) crown density is in a strict correlation neither with tree growth nor with the remaining life-time of the tree.

In spite of this critisism the variable "crown density" is continuously used, because no constructive suggestions have been made regarding a more appropriate variable. Many variables are well suited for laboratory investigations and in intensive studies on small plots but none of them have as yet been developed for use in large scale assessments.

Needle discoloration is another simple variable that has been applied. It involves the same problems as crown density but in many areas also needle discoloration is regarded a useful variable. - Intensive research is needed to examine the measurement techniques of crown density and needle discoloration and also to search other variables suitable for large scale damage assessment. Special emphasis should be given to examining the potential of aerial photography and remote rensing.

The impact of damage on stand growth and tree mortality would need to be studied in detail in the future. Tree growth has been related to crown density in a nation-wide inventory at least in Sweden. Permanent plots can not be used for this purpose because sampling a tree-ring core is a potential damage to tree. Additional temporary plots should be used, therefore, giving proper emphasis to the statistical procedure in establishing those plots. In national surveys they should be connected to the network of the permanent plots. Data analysis should pay much attention to constructing the time series of the volume growth of entire stands rather than just looking into the time series of ring width. Models are needed for taking into account the climatic factors as well as the factors that are site-specific, species-specific or related to tree age and stand development. All these procedures are scientifically rather demanding.

42. Sample plots

A systematic grid of sample plots has been used when conducting statistically valid assessments of forest damage. Clustering has been applied in order to reduce the costs of measurement. Accuracy of the results from this type of data can be calculated on a routine basis.

Permanent sample plots are established for monitoring purposes. When establishing these plots it is of utmost importance that the authorities and the forest owner do not know the exact location of the plot. Otherwise the sample no longer remains unbiassed. Permanent plots must be selected systematically or at random thus ensuring that the stand age distribution, tree species distribution etc. adequately represent those of the forest region.

In regional surveys trees could be sampled using a relascope and thereby increasing the propability of large trees to form the sample. It is easier, though, to apply fixed-area plots in which plot boundaries do not grow or shrink over the interval between two measurements. From the statistical point of view it is effective to maximize the number of the plots. There is a certain minimum size for the plot because many variables make sense only when measured as the average of at least 5 or 10 trees. Measuring very small plots is neither cost-effective. Small plots can be used in dense forests and vice versa.

43. Sample trees

Two levels of intensity can be used in selecting the sample trees. The first level is used for measurements that are fast to carry out such as tree species, breast height diameter (D 1.3) and, perhaps, crown density. The second level will include less trees so that more laborious measurments can be taken (e.g. other stem diameters, more detailed canopy variables and measurement of epiphytic lichens).

In monitoring programmes a method must be developed such that the sample trees can be identified after the time interval betweeen two measurements. No obvious numbers or signs should be left on the trees because they might influence the treatment of the stand.

New sample trees are needed to replace those that have been removed or that have died. A sound statistical procedure should be developed also for the selection of the new sample trees. It may be more adequate in practise to establish new permanent plots rather than to select new sample trees from the old plots. Newly established monitoring networks do not need such a replacement very soon so that there is plenty of time for solving such problems.

44. Timing of measurement

Many forest variables are subject to a seasonal cycle, and this causes a problem of the proper timing of the measurement.

Sometimes it may not be possible to conduct the measurements within a specific time of the season. One solution then is to take measurements from different parts of the region throughout the summer but to do that in a randomized order so that the seasonal variation is included in the "noise". Another option is to describe the seasonal pattern of each variable in different parts of the region and to standardize all measurements to correspond to, say, high summer values. Such corrections are technically rather demanding because the correction coefficients must be derived from a sample which represents all forests in that region. If this requirement is not fulfilled then there will no longer be a possibility of quantifying the accuracy of the results.

In all monitoring programmes it may be cost-effective to measure large samples at relatively long intervals and select small subsamples for more frequent measurements. This way it will be possible to "zoom" the ecosystems for more detailed investigations and yet maintain the statistical basis for generalization. When so doing it is of ultimate importance that the subsample is an unbiassed statistical sample with reference to all the variables that are included in the measurement scheme.

5. Data analysis

51. An example

Measurements of this example are taken from a plot of 300 square meters located in Central Finland in a 65-year-old pure stand of Norway spruce. 20 trees within the plot correspond a stand density of 667 trees per hectare. Six trees, with average height of 19.7 m, are classified as dominant trees. When looking into the distributions of tree height, tree diameter, stem basal area, stem volume and crown density it is obvious that defoliation in this stand is concentrated in large trees (Fig 2a-2c).

52. Output variables

521. Mean crown density

The arithmetic mean crown density of 20 sample trees is 81.5 per cent. For the 6 dominant trees it is 78.3 per cent. The arithmetic mean crown density weighed with tree basal area is 78.2 per cent, and that weighed with tree volume is 76.9 per cent (for all 20 trees).

522. Fraction of resource damaged

Following a definition that all trees with crown density of 80 per cent or less are damaged we find that 45 per cent of the trees on this plot are damaged (Fig 3a). Weighing the distribution with stem basal area the result is obtained that 53 per cent of the resource is damaged (Fig 3b). Similarly, weighing the distribution with stem volume it appreas that 61 per cent of the resource is damaged that is, trees with a crown density of 80 per cent or less contain 61 per cent of the total volume of the trees on this plot (Fig 3c).

523. Amount of the healthy resource

On way to analyse how severe is the damage is to assess whether or not there is a sufficient amount of healthy trees (or basal area, or volume) to form a satisfactory forest stand. Using data from this example plot one may first look into just the dominant trees and consider supressed trees as unimportant. The six dominant trees exhibit crown density values of 60; 60; 70; 90; 90 and 100. Three dominant trees have crown density values of 80 or more. That corresponds to 100 trees per hectare, or 5.8 m^2 of basal area and 51 m^3 of volume per hectare. These results can be compared to the standards that are available for 65 year-old spruce stands growing on this kind of site, and in this way develop additional variables to gain more information about the damage.The size of the plot in this example may be somewhat too small for justifying this type of variables.

524. Other variables

It is very difficult to judge in a general way what kind of variables, in fact, would be the important ones. Very much depends on the nature of the forest area. For commercial forests, used mainly for timber production, damage to old trees may not be important because the rotation period is short anyway. For national parks damage to old, the most beautiful trees may be just the most important thing.

Scientists should be invited to develop new variables. Leaving the discussion open to any new suggestions for data analysis is an effective way to learn more about the nature of forest damage. New understanding will then serve as a basis for reducing the damage.

6. Conclusions

Large freedom in choosing the method of damage survey assists in taking into account the national characteristics as regards forests, pollution problem, personnel, tradition and the available resources. It also promotes innovative ideas of gaining new information. Some limits to this freedom are needed, however, to obtain comparable results from various countries. A compromise is suggested that strict requirements are agreed upon the principle of the sampling method. Sample plots must be distributed into forest in an unbiassed manner so that they represent the whole forest region. Sample trees must also be chosen in a statistically stringent way. A basic set of key variables are defined as obligatory variables. Free choise is allowed for sampling intensity, for the details of sampling technique and for additional variables.

All data is submitted to the Coordinating Centres that are requested to carry out extensive data analysis. Scientists from participating countries are invited to develop new methods of data analysis that would improve the understanding regarding forest damage. The coordinating activity should be viewed as a continuous process that should last for at least ten years.

APPENDIX

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DATA VARIABLES

(1) General:

- country
- forest region or administrative unit
- x/y co-ordinates
- elevation
- date of record
- topography: direction of slope
  slope steepnes
  position on slope
- distance of the center of the plot
  from the edge of the stand/type
  from sources of emission (road, settlement, field, others)
- recent changes in site conditions

(2) Soil data:

- land class
- mineral soil/peatland
- yield class
- ground vegetation
- soil type (FAO-classification)

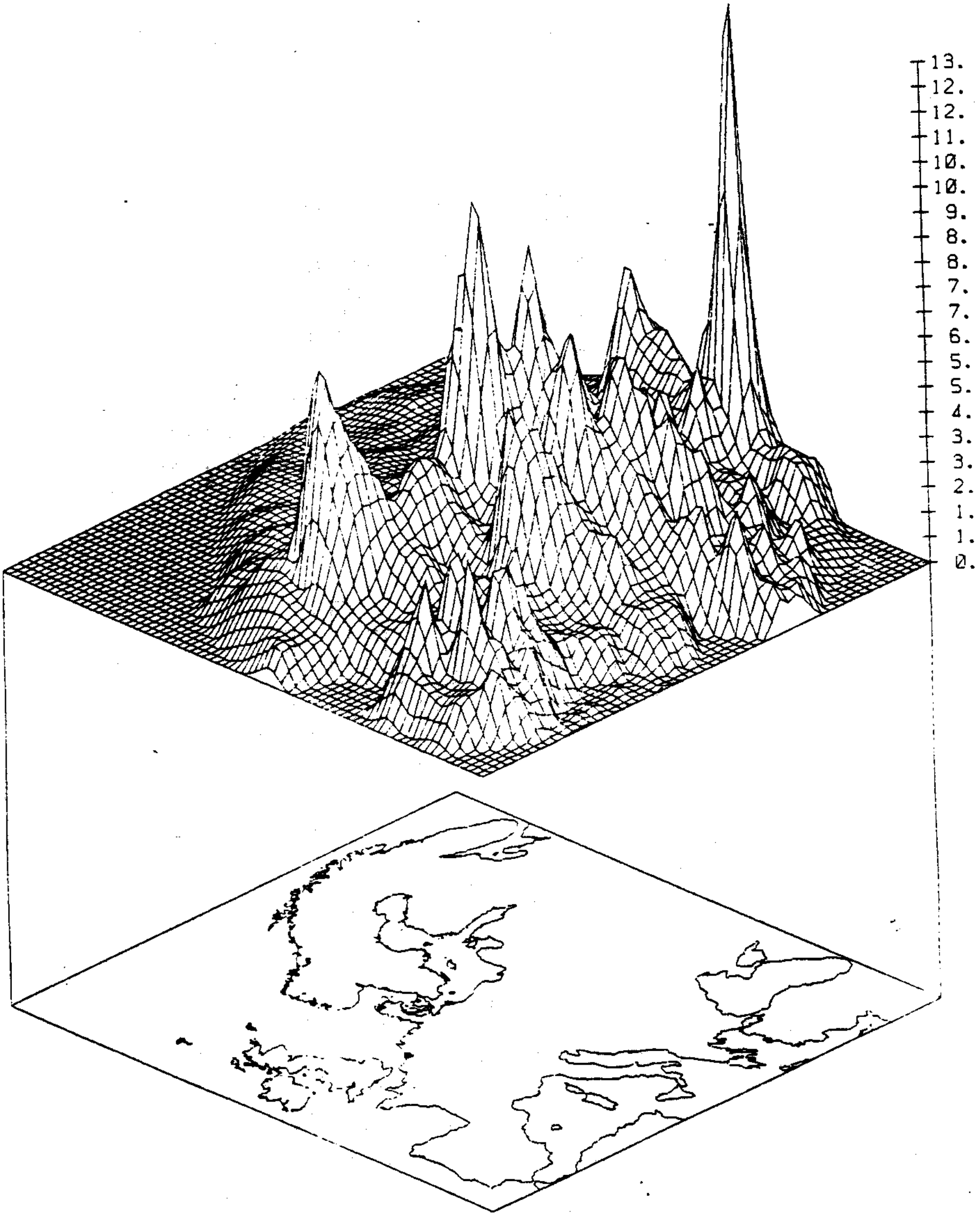
(3) Stand data:

- tree species
- age class
- development class
- basal area
- recent fellings: type/time of occurrance
- damage: top/crown/trunk
  obsious reason for damage
  damage silviculturally significant/insignificant
- crown density
- discoloration
- epiphytic lichens: species/abundance

(4) Tree data:

- tree number
- azimuth and distance
- tree species
- crown class
- diameter at breast height (DBH)
- height
- lowest limit of the living crown
- damage: top/crown/trunk
  obsious reason for damage
  damage silviculturally significant/insignificant
- crown density
- discoloration
- epiphytic lichens: species/abundance

Figure 1. Sulphur deposition in Europe in 1980. ($g \cdot m^{-2} \cdot yr^{-1}$). Data from ECE-EMEP, graph from IIASA.



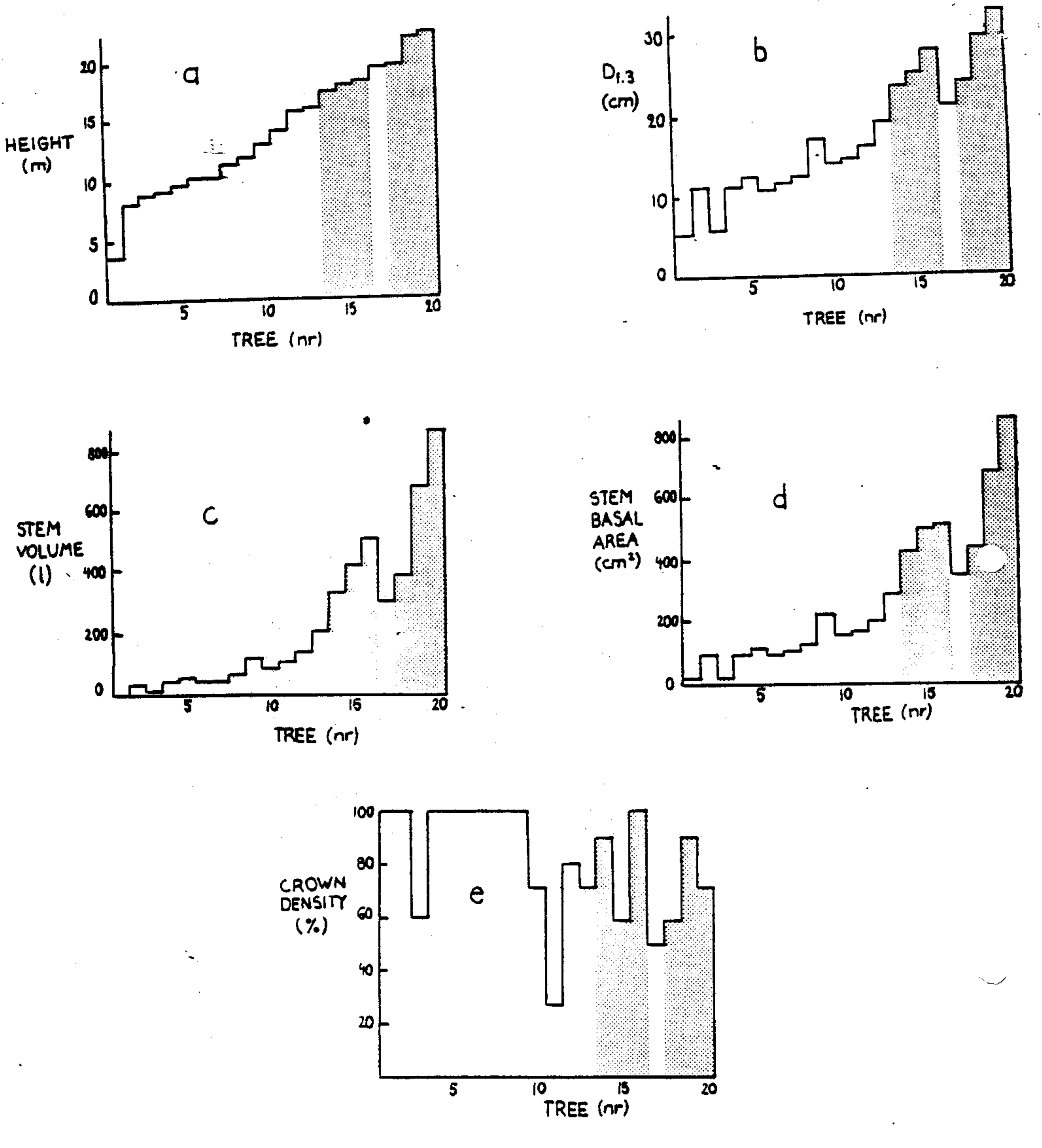


Figure 2. Example plot of 300 m^2 with trees numbered from 1 to 20 in ascending order with tree height (a). Six trees indicated with dashed bars were considered dominant or codominant trees (14; 15; 16; 18; 19 and 20). Distributions of D 1.3 (b), stem volume (c), stem basal area (d) and crown density (e) are presented with the same fixed numbering on horizontal axis.

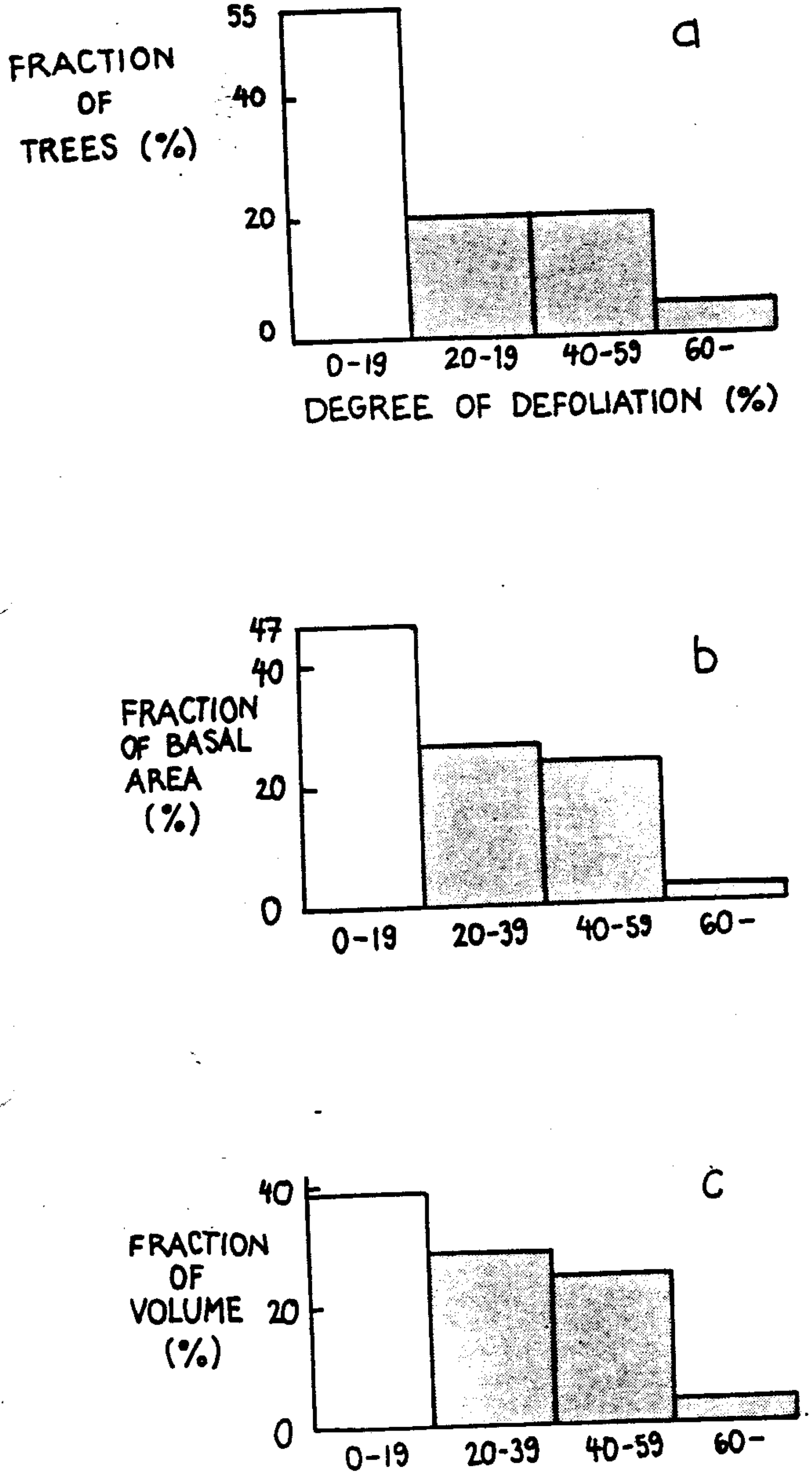


Figure 3. Fraction of resource damaged (shaded bars).