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F. Mahrer

Federal Institute of Forestry Research, CH - 8903 Birmensdorf
Switzerland

APPLICATION OF AERIAL PHOTOGRAPHY IN THE SWISS NATIONAL FOREST INVENTORY (NFI)

Abstract

The possibilities of a multiphase sampling strategy for use in the not yet established NFI are explored. Since emphasis is placed on recognizing structural changes or changes in forest use, a permanent sampling network is planned. The time required to locate and secure the sample plots on the ground and to take the dendrometric measurements is critical for the total inventory costs. To minimize ground work, the sample plots are inspected, classified and selected for ground inspection beforehand on the panchromatic aerial photographs (medium scale 1 : 25,000) which have been taken every six years by the Federal Aerial Survey. On the photographs the samples are located analytically, using an automatic procedure.

This presentation gives a summary of the purpose and objectives of the NFI and describes a two - stage sample survey to be tested over a large area. The determination of the forested area on aerial photographs, based on quantitative criteria, is particularly treated.

1. The Swiss National Forest Inventory (NFI) concept

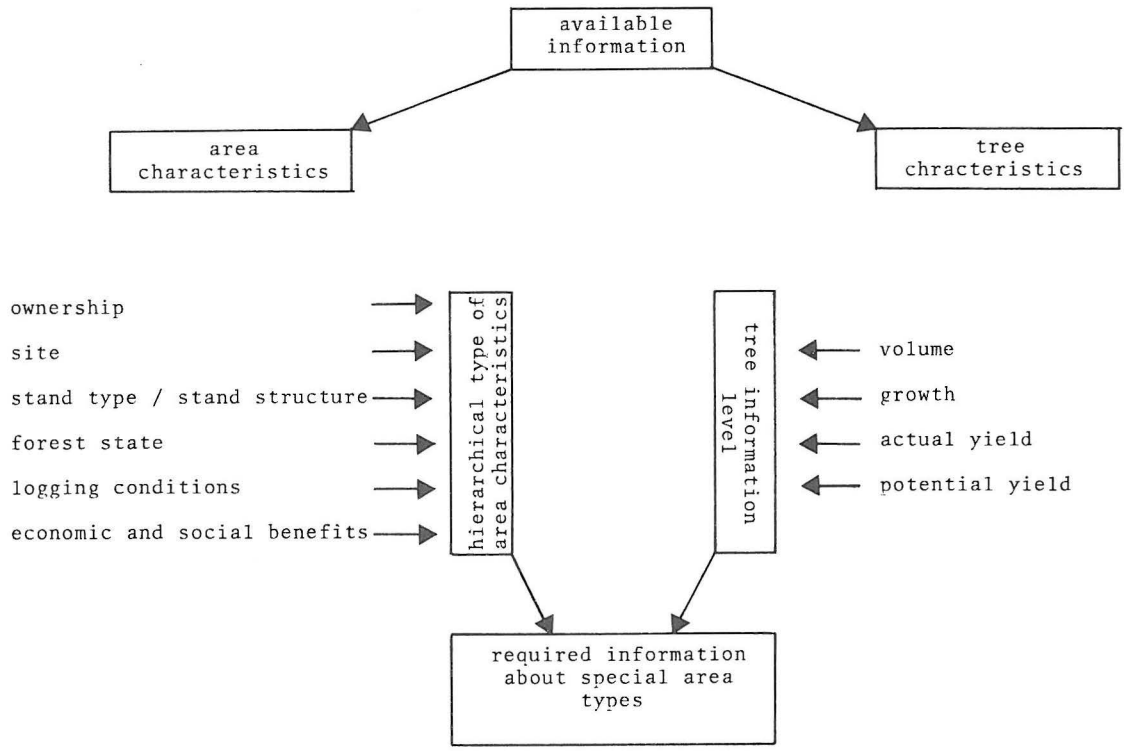
Up to the present, in various countries forest surveys have been carried out by means of sample surveys. In Switzerland an NFI has been discussed since the fifties; not until 1973 was the new division "National Forest Inventory" at the Swiss Federal Institute of Forestry Research charged with the preparation of this great assignment.

The general aim of the NFI consists in providing information for forestry and timber economy and in particular for the problem area of the public interest in forests such as general land use planning and the determination of the social-economic role of forests. In this sense, the planned inventory is expected to exceed the existing forest surveys of other countries. In Switzerland the related essential political decisions are made by federal and cantonal authorities. In terms of data collecting and size of information units, a national forest survey has therefore to be designed to the needs of the federation and the cantons. The forest area of Switzerland amounts to one million hectares distributed very unevenly over the 26 cantons. Therefore the required information units are small and a relatively high sampling ratio is necessary. The determination of the desired information is probably more difficult than it seems at first sight. Flexibility with regard to possible problem situations has to be taken into consideration in the definition of the desired information. As an example the consideration of arrangements for forestry in case of a possible energy crisis is mentioned. According to experience, factors enabling such arrangements to be made can be found ad hoc only inefficiently, if at all. In addition to static information, the data describing changing conditions will have a major influence upon political decisions. If the NFI is to provide the required data, a *comprehensive program* is needed as a permanent assignment, as a *permanent sample survey*.

In a first step the required information had to be expressed in terms of practicable survey data. The available primary data of a forest survey can be devided into "area" characteristics and "tree"

characteristics. Every analysis of these primary data refers to a certain area. This may be the total survey area or can be only a special area type, a subset of samples with specified combinations of characteristics. Depending upon the level of information, the tree characteristics can be related in more or less detail to such area types. The larger such an area is, the more detailed the information which can be provided with an acceptable error. The required information as a combination of area characteristics and tree information at the required level can be shown as a hierarchy for the survey area. Figure 1 shows area and tree characteristics divided into information groups.

Figure 1



The information to be furnished is an important factor in the survey planning, but there are also other elements which are essential to the determination of the survey method for an NFI. In particular the political conditions for the inventory have not yet been fixed in every detail. Research on the survey technique is still going on. The actual progress achieved at the beginning of the survey and finance available will determine the attainable aims of an NFI. The application of aerial photography in the NFI must be considered accordingly.

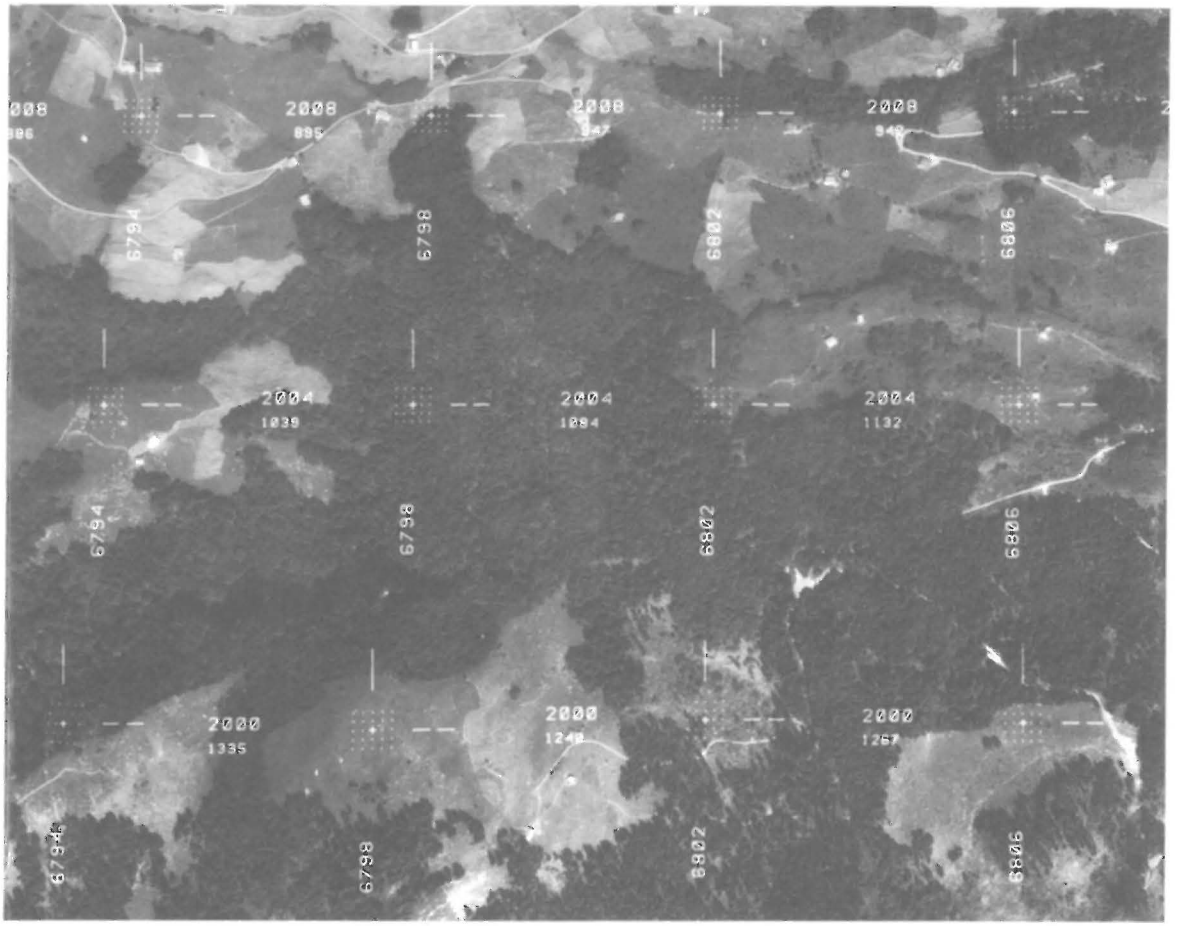
2. Photo interpretation as a survey phase

The results of research work on inventory methods carried out at the Swiss Federal Institute of Forestry Research suggest for the NFI a multiphase sampling technique (1). This technique proved suitable for the volume estimation in a low densitiy subalpine coniferous forest (2). The total volume is calculated by regression analysis, based upon a systematic sample network with a high sampling ratio on aerial photographs and a terrestrial sample plan with a low sampling ratio. In 1978 a test over a large area was started in order to get all important components for such a survey technique. The objective of this test is to determine an optimal survey method by comparing different combinations of the survey phases with regard to expenditure and information value. This test is carried out in a entire canton which, with a forest area of 9,800 hectares, represents a realistic information unit. The sampling ratio for the photo and map interpretation (phase 1) was one sample per 4 hectares and for the terrestrial survey one sample per 16 hectares. The sampling ratio for phase 1 is based on a maximum relative standard error of 1 % for the total forest area (confidence level 95 %). The sampling ratio for the terrestrial survey is based on the assumption that the relative standard error of the total timber volume per hectare determined on the ground must not exceed 5 % (confidence level 95 %). In the following text the application of aerial photography in this test survey is emphasized.

In the first step the sample *network* of phase 1 has to be *transferred* onto the aerial photograph and onto the map. Maps and aerial photographs are available for the entire country at a medium scale of 1 : 25,000 and are updated every six years. For each sample, elevation, exposure, inclination and topography are determined on the map. In the same step the coordinates of the reference points for the analytical orientation of the photographs are measured and subsequently, the orientation elements of the aerial photographs are calculated. Thereupon the image coordinates of the plot centres and the surrounding grid points are calculated and plotted, using the reference point measurement on the

photographs by means of a comparator and previously determined map information. For the photo interpretation the sample plots and the surrounding grid points are copied onto the photograph (figure 2). The method of point transfer is described elsewhere (3).

Figure 2



In the course of the *photo interpretation* the plots falling into forest area are determined first. The area inventory, which includes the determination of the forest area and its distinction into forest types, will be treated in the next chapter. For the forest samples only, which amount to approximately one forth of all samples, growing stock is rated and measured next. The qualitative interpretations, stage of stand development, proportion of mixture and forest structure serve mainly for the purpose of stratification. To quantify the relationship between timber volume, measured on the ground, and tree characteristics visible in

aerial photographs, certain variables such as crown cover, height and crown diameter of dominant trees are measured in each plot. These measurements are being made at the Institute of Photogrammetry at EPFL in Lausanne.

The next step of the survey process is the topographical *map interpretation* of forest samples. The parameters yielded by the map are used for the estimation of forest road network, the calculation of a site index, and the accessibility of the sample plots which is an important factor of expenditure for the terrestrial survey. The methods of determining the forest road net and the accessibility (4) as well as a key for rough estimation of site productivity (5) are published elsewhere.

The *terrestrial survey* is the final step. The ultimate goal of the manifold ground inspection programme is the determination of timber volume by dendrometrical data and, in subsequent surveys, the recording of growth and actual yield. In the whole test region concentric single plots of 400 m^2 for closed stands and 1,000 m^2 for stands of low density were systematically sampled. All terrestrial samples are located (azimuth, distance) from marked fixed points and secured as permanent sample plots.

It became apparent that the aerial photographs were an important aid for measuring and locating the ground plots. Especially in the mountainous region, a topographical map furnishes only a few points which are suitable for the calculation of azimuth and distance to the plot to be measured. The aerial photograph, however, shows, especially in such regions, many easy recognizable details, suitable for fixed points. Within the surrounding grid points 10 m apart from each other (figure 1), the coordinates of such fixed points can be determined exactly. Using aerial photographs it was possible to reduce the distance from sample centre to fixed point for samples above an elevation of 1,000 m by more than 60 %.

It appears to be feasible to optimize the sampling plot ratio (ground inspection / photo interpretation) based upon the data of the extensive test programme. Considering financial aspects and legitimate demands, this ratio is of a crucial relevance for the NFI.

3. The determination of the forest area in the NFI

The determination of the forest area and its changes is one of the important aims of the NFI. This goal can only be reached by an objective definition of "forest" based on quantitative criteria used in consecutive surveys. In an efficient survey a terrestrial determination of the forested area is excluded. Permanent samples in aerial photographs are most appropriate here.

The practical application of information from a forest area survey is essentially limited by the possibilities of differentiating the total forest area (main category) into forest types (sub-categories). The classification of the entire forest area requires in this case that each forest type can be determined objectively and that it corresponds to an average productivity of the growing stock. For an efficient survey it is very important that the specifications of the different forest types are adapted to the possibilities of aerial photograph interpretation which limits terrestrial verifications to a minimum.

The definition of "forest" is shown in a simplified diagram. Numerous special cases and details are discussed in the literature (6).

Criteria for forest delimitations are the following quantitatively definable parameters: *Width* of stocked area, *crown cover* and *dominant height*. To apply these criteria accurately, the limits of the stocked area have to be defined by the line connecting those trees which are less than 25 m from each other. Trees and bushes lower than 3 m are not taken into account. The reference for the measurement of the parameters mentioned above are the surrounding grid points, which are copied onto the aerial photograph (figure 2); they cover an *interpretation area* of *0.3 ha*. The measurement is always related to the stock within the delimited area. The relevant criteria are tested in the following order:

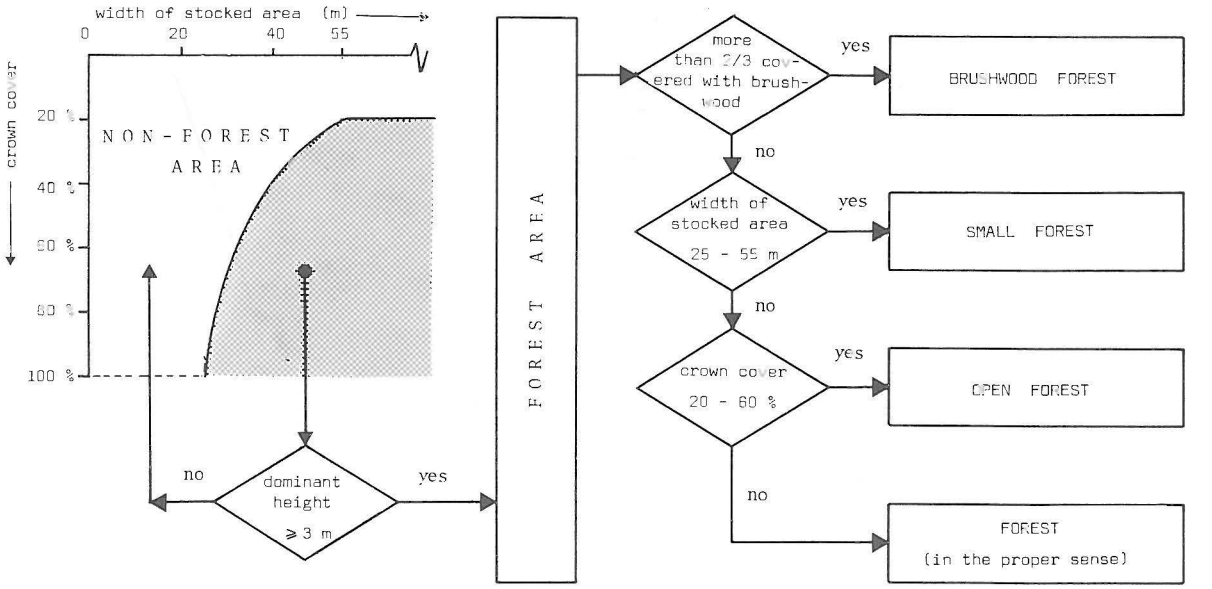
Width of stocked area: The shortest distance from one side of the area to the other, measured through the centre of the sample plot, is defined as width. The required *minimum width* for the main category is fixed at *25 m*. Width is also used for the delimitation of the sub-category "small forest".

Crown cover: Crown cover is defined as that portion of the area covered by the crowns relative to the total stocked area. The required *minimum crown cover* for the main category within the stocked area is usually *20 %*. If the width of the stocked area is between 25 and 55 m, the required crown cover must be more than 20 % (figure 3). Crown cover is measured on the interpretation area of 0.3 hectares, containing 25 grid points; each point of the surrounding grid falling on a crown represents a crown cover of 4 %. Crown cover is also used for the delimitation of the sub-category "open forest" (figure 3).

The relation between width and crown cover: In order to be considered as a "forest" a relatively small stocked area must exhibit a larger crown cover as compared with a larger stocked area. It was determined that the crown cover of the smallest area admissable (25 m x 25 m) must be 100 %. Such a totaly covered minimum area of approximately 600 m^2 is required for all areas. The relation shown in figure 3 is based on this prerequisite. With a minimum width of 25 m a crown cover of 100 % is required, and a width of 55m (corresponding to the interpretation area of 0.3 ha) requires a crown cover of 20 %.

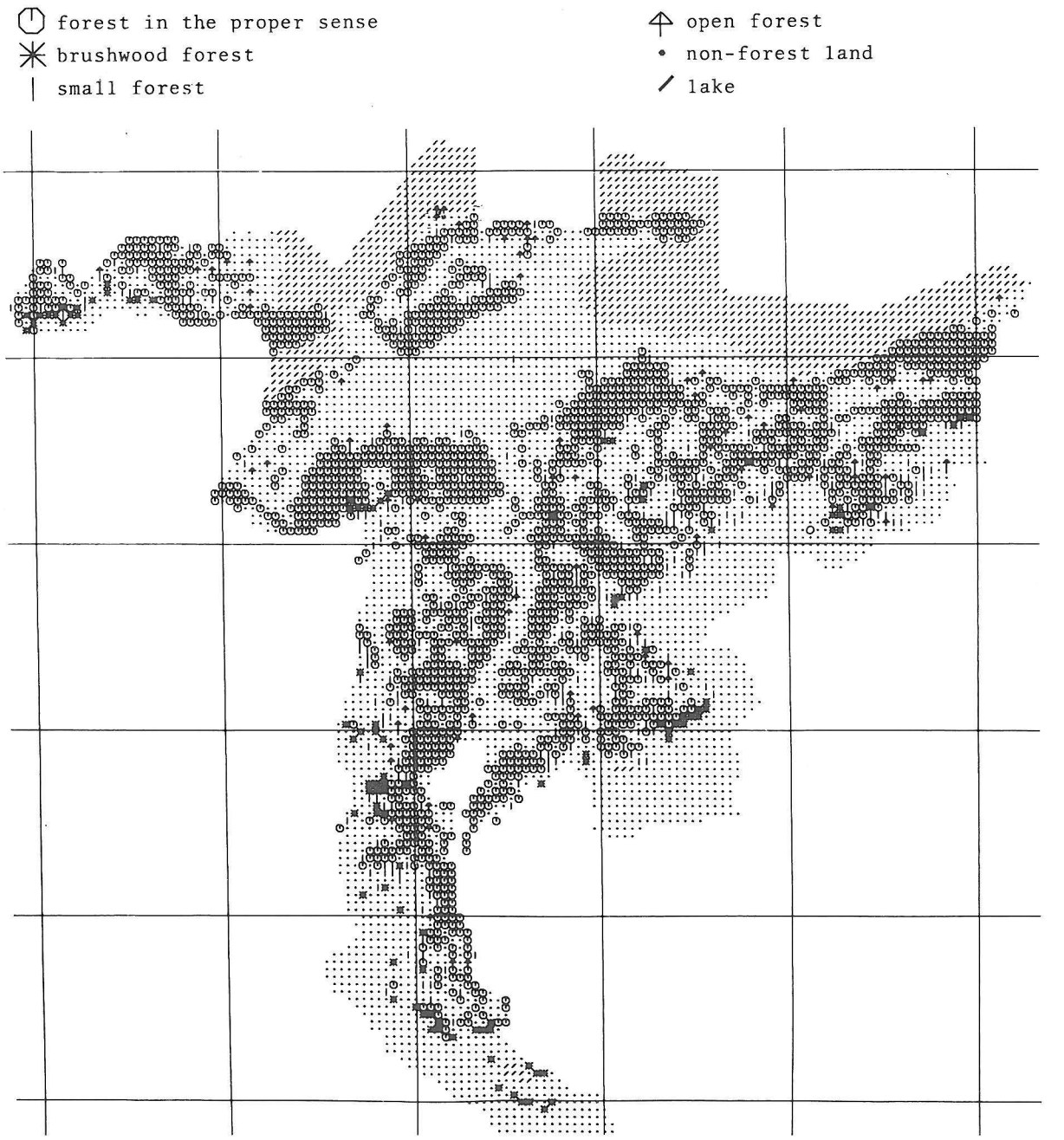
Dominant height: The required *minimum dominant height* is fixed at *3 m*. This height is estimated on the stereo-picture by comparison with objects of known height. In regenerations and afforestations this criterion is not considered.

Figure 3



The result of the forest area survey in the test region is shown in figure 4. The position of each plot is defined by its coordinates. Hence the evaluated forest area can be mapped by a printer or by a plotter as shown in figure 4.

Figure 4



Maps are an important complement to statistical data from surveys, because only maps show the spatial distribution of the different characteristics. One reason for considering this distribution is the estimation of the sampling error. Assuming a random distribution of the

characteristics with regard to a systematic sample network, the variance can be calculated using the binomial formula. For the test region a relative standard error of 1.2 % (confidence level 95 %) results. If the characteristics are not randomly distributed, as in case of our test region, the sampling error is overestimated. The bigger the "clustering" of a characteristic with regard to the systematic network, the smaller the variance. There are different more or less suitable methods which account for autocorrelation and which supply estimates adapted to the distribution. For the NFI the Quadruplet-Method of Matérn (7) was applied for the test area data. This method yields a relative standard error of 0.9 % (confidence level 95 %). A sample densitiy of one sample per 4 ha gives a total forest area of 9,797 ha $\pm$ 89 ha in the test region.

The question to which extent aerial photography will be applied for the future NFI is not settled yet. At this point it is certain that aerial photography will be an important aid in the area survey and the localization of terrestrial sample plots.

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