

## 2.2 Aerial Photography

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### 2.2.1 Introduction

From the beginning, aerial photography was incorporated into the inventory design of the NFI as one of its most important data sources. While aerial photography mainly served to determine the forest area and to measure reference point data for the terrestrial survey in the NFI1, the NFI2 extended the catalog of attributes measured in aerial photographs. Apart from area data, stand data, and tree data, new attributes were added that refer to areas outside of the actual forest (Chapter 2.2.6).

The most striking difference between the NFI1 and NFI2 is the extent of the airphoto interpretation. The NFI2 was designed as a double sampling inventory (Chapter 1.1.3). Auxiliary variables were measured in the first phase (airphoto interpretation). In the second (terrestrial survey), the actual variables of interest were measured. Compared to the NFI1, the number of field samples was reduced by half to approximately 6,600, and the number of aerial photo samples quadrupled to a total of about 165,000. Because of this the precision in the forest area estimation increased. Due to this fact, and due to the stratification in aerial photographs, it was possible to obtain similar standard error values, such as for the estimation of the standing volume, as compared to the NFI1 (Chapter 1.1.4).

For the aerial photo sample plots, a square sample grid with a 0.5 km mesh width (0.5-km-grid) was chosen. For the terrestrial sample plots a coarser grid with 1.4 km ( $=\sqrt{2}$  km) mesh width (1.4-km-grid) was chosen. The 1.4-km-grid and the 1.0-km-grid of the NFI1 are subsets of the 0.5-km-grid (Figure 1). The second terrestrial grid – a 4.0-km-grid shifted by 0.5 km – was taken as an independent sample in order to verify the representativeness of the NFI2 sample plots.

### 2.2.2 Goals

The following goals were set for the airphoto interpretation:

1. **To identify forest area:** Each aerial photo sample plot was classified according to defined assignment rules: the so-called “Forest/Non-Forest Decision.”
2. **To measure reference points:** The coordinates of reference points were measured to help the field survey team determine where to locate the sample plot centers by using these measurements.
3. **To prepare for stratification:** Stand attributes were measured and were used as stratifying variables for the statistical analysis of the field data.
4. **To assess stocking outside the forest area according to NFI:** In all of the aerial photo sample plots, stocking and individual trees were recorded independently from the “Forest/Non-Forest Decision.”

The NFI1, as well as the NFI2, were primarily designed to record the current state of the forest. In addition, the NFI2 was also designed to record changes. Therefore, Goals 1, 2, and 3 were the principal focus of the airphoto interpretation. Goal 4 was formulated to meet the needs for data concerning occurrence, type, and distribution of small wooded areas, hedges, and individual trees outside the actual forest area, according to NFI forest definition. In Switzerland, the information about these types of stockings is in demand because of the important role they play as ecological islands in a landscape formed by strong anthropogenic influences. Furthermore, this information is also taken into account in international statistics to estimate the total biomass of a country.

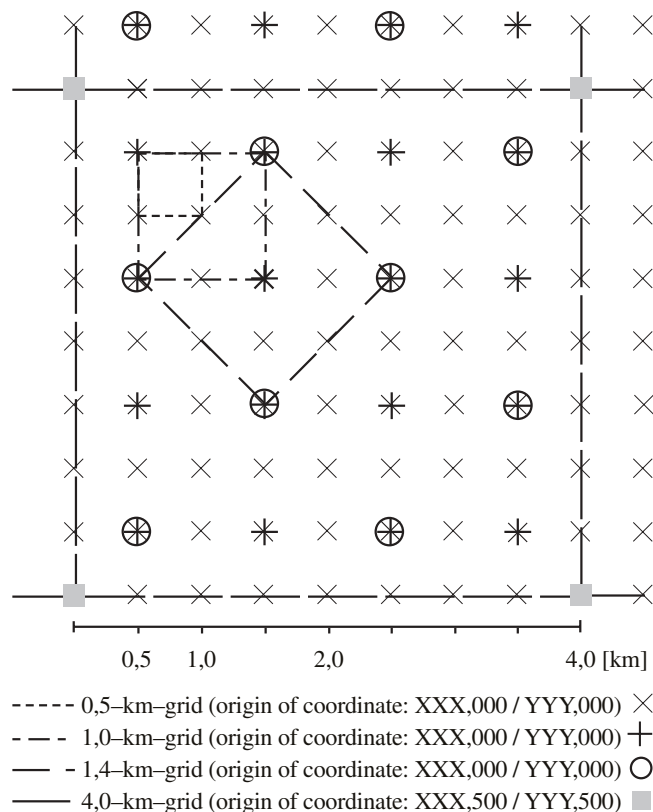


Figure 1. Sample Plot Grids for the National Forest Inventory.

### 2.2.3 Airphoto Interpretation

The airphoto interpretation in the NFI is based on the application of photogrammetric procedures with analytic plotters. During the analysis, pairs of aerial photographs with stereoscopic overlap areas (stereopairs), are studied as three-dimensional images that are photogrammetrically analyzed and interpreted.

#### 2.2.3.1 Aerial Photographs

As with the NFI1, the NFI2 employed aerial photographs from the Swiss Federal Office of Topography's regular flight program to update the national maps of Switzerland. Every year about one-sixth of Switzerland is photographed in black and white from the air. Figure 2 gives an overview about the flight years of the aerial photographs interpreted for the NFI2 and provides an account of how current their information is.

In the regions north of the line Murtensee – Zugersee – Walensee, in the southern part of the Walliser Alps, and in the Southern Alps, the time span between the aerial photographs and the field survey in the NFI2 took four to six years longer than in the NFI1. In western Switzerland the time span was about the same as in the NFI1. In the remaining alpine regions of the cantons Valais, Berne and Grisons the time span was one to two years shorter.

The reasons for these differences are found to be: (1) slightly altered flight plans and (2) extended airphoto interpretation which took more time than anticipated. Due to logistical reasons the interpretation always had to be finished before the field surveys, thus it was not possible to employ the newest aerial photographs in all regions. Chapter 3.2 explains how the regions different time intervals between the first and second survey were considered during the analysis.

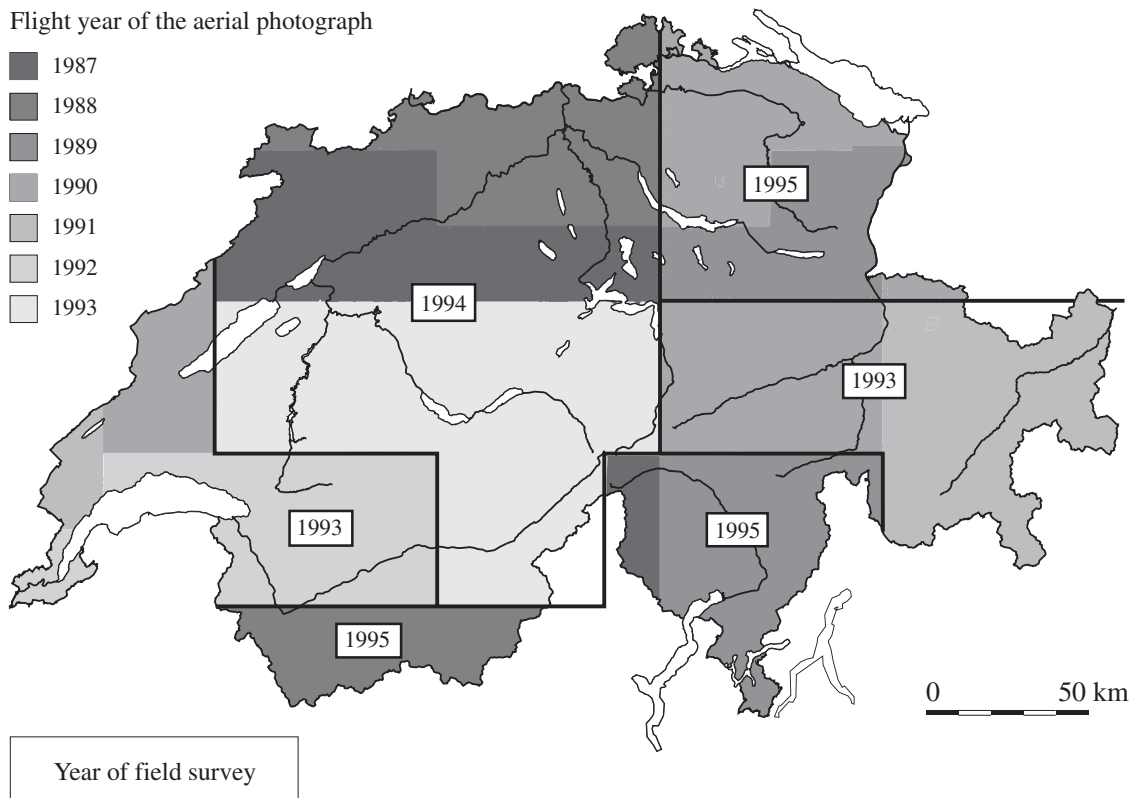


Figure 2. Flight Years of the Swiss Federal Office of Topography.

The aerial photographs employed for the NFI1 and NFI2 did not only differ with respects to their current information, but also in part with respect to their scale. The NFI1 aerial photographs were available with a scale of 1:25,000, while the NFI2 aerial photographs were interpreted at a scale of 1:30,000. This affected the aerial photographs that were taken with the mapping cameras from type “Leica RC-20” and “Leica RC-30.” Both cameras were equipped with a device to compensate for the blurring effects caused by aircraft motion in flight direction during the time the photograph was taken (FMC = Forward Motion Compensation). Aerial photographs that are taken with these types of cameras usually have a sharper image than older aerial photographs and make it easier to measure small objects. Consequently, it cannot be ruled out that in individual cases, as a result of better image quality, airphoto interpretation leads to different results as compared to aerial photographs that were taken with an older camera type (i.e., “Leica RC-10”).

### 2.2.3.2 Photogrammetrical Analysis Instruments

The airphoto interpretation was done on two workstations equipped with an analytic stereoplotter (“Leica DSR-1/15” or “Leica DSR-15”). A precision drawing table “Kern-GP1” was available for the output of digital measured values onto engraving foil or paper. Both instruments were controlled by a DEC-computer (“Microvax-3900” or “Microvax-3400 operating system VAX/VMS 5.2). In addition, two analog stereoplotters “Wild-APT1” were available for comparison with aerial photographs from the first inventory. A conventional 35 mm camera can be mounted on these instruments to reproduce details from aerial photographs.

All photogrammetric instruments are equipped with a second ocular that allows two people to look at the same stereo model simultaneously. This way it is possible to control and improve the reliability and quality of the interpretation through direct observation. Chapter 2.10 “Control Survey of the Aerial Photography Interpretation” examines the reproducibility of the aerial photography interpretation.

### 2.2.3.3 Workflow

The airphoto interpretation was carried out in four steps (Figure 3):

1. Data preparation
2. Orientation
3. Interpretation
4. Storing of the analyzed data within the database

### 2.2.4 Orientation of the Pair of Aerial Photographs

According to HILDEBRANDT (1996), “one understands that by the orientation of an aerial photo pair first of all the mutual orientation of the images in a way that all homologous rays intersect. With that the rays of both images are restored in their correct orientation to each other.” If, in addition to this, the lateral and longitudinal inclinations of the aerial photographs are also considered, it is then called “relative orientation.” Nevertheless, the relative oriented model is not determined with respect to its position in space. Only the absolute orientation establishes the reference of the relative oriented model to the terrain coordinate system.

The following briefly describes the steps that lead to an absolute orientation, and the established precision standards for the NFI are stated. Further information about the theory and mathematical derivations of the individual steps are described in detail in well-known standard books, like KRAUS (1990) or HILDEBRANDT (1996).

#### 2.2.4.1 Data Preparation

For the orientation of stereopairs, the appropriate set of base data has to be available. To these data belong specifications about the mapping cameras and lenses used during the flight; the data from the data strip on aerial photographs, along with information about the photographed terrain section. Information about the photographed terrain section was taken from the national maps with a scale of 1:25,000. These essential data were directly needed for the orientation, as well as to identify the stereo model. These data were stored following the first orientation together with the orientation parameters in the data bank. For all further interpretations of one stereopair, such as to examine the reproducibility of attributes, it was sufficient to perform the interior orientation (see below) and to extract the other orientation parameters from the data bank.

Ground control point and reference point data also belong to this data basis. In the NFI1 they were measured for the orientation of the aerial photographs and the terrestrial location of the sample plot center. They were also used for the orientation of the new aerial photographs in the NFI2.

#### 2.2.4.2 Interior Orientation

In a mapping camera – in contrast to a normal, non-calibrated camera – the relationships between the incoming bundle of rays and the created aerial photograph is determined through calibration. The values of the “interior orientation” of a mapping camera are recorded in the calibration protocol. For the interior orientation of a mapping camera, the calibrated focal length, the position of the principal point, and the parameters used to compensate for optical inaccuracies like distortion or chromatic aberration, have to be known. The parameters specific to each camera are taken from the calibration protocol, and the position of the principal point is then calculated from measurements of the fiducial marks on the aerial photograph.

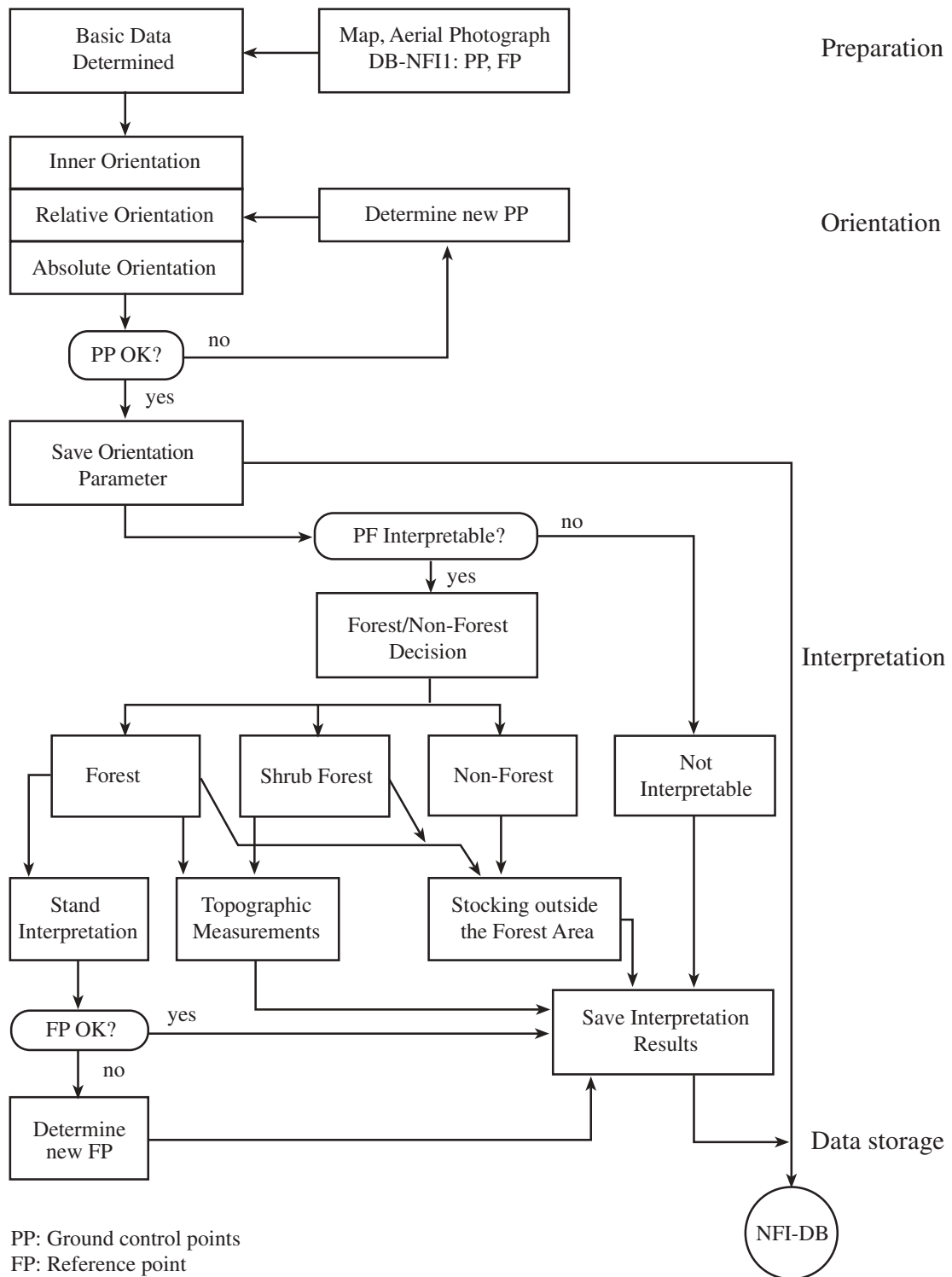


Figure 3. Process of the Airphoto Interpretation.

The analytical stereoplottter is equipped with a double-image carrier, which is free to move in the plane and onto which aerial photographs can be fixed. In each aerial photograph the interpreter measures the position of the four fiducial marks. The actual value of the fiducial mark coordinates is compared to the desired values from the calibration protocol of the mapping camera, and the resulting measurement error is calculated. The residuals for the x- as well as the y- coordinates are not allowed to exceed 10 µm.

### 2.2.4.3 Relative Orientation

During the relative orientation, the spatial position of the image plane at the time the image was taken is reconstructed. By reconstructing the heading, roll, and pitch angle, each aerial photograph of a stereopair is brought mathematically into the same spatial position relative to the earth's surface as it was at the time of exposure. Simply stated, by shifting both photographs of a stereopair, they are brought into a position in which the observer can perceive them as a three dimensional model.

In order to accomplish this, the interpreter selects in the stereoscopic overlap area of the stereopair eight evenly distributed tie points, which are well visible both in the left and in the right image. Both aerial photographs are shifted against each other until all eight tie points in the left aerial photograph line up as precisely as possible with the ones in the right aerial photograph. Ideally, from these measurements the computer of the analytical stereoplotter calculates a parallax free stereo model. With this, the stereopair is "relatively oriented" and can be seen by the interpreter as a three dimensional image.

As compared with the normal procedure according to GRUBER (KRAUS 1990), which uses six tie points, the eight tie points produce a better result for analytic stereoplotter (ZUTTER, oral communication). This statement was examined and confirmed in the course of the pilot inventory for the NFI2. Figure 4 shows the distribution of the eight tie points in the stereo model.

The relative orientation is stepwise optimized until the position error of the x- and y- coordinates for each individual control point is at most  $\pm 7 \mu\text{m}$ .

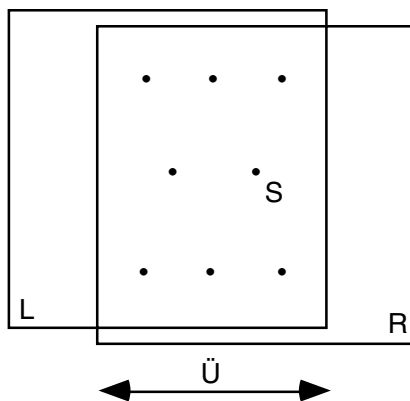


Figure 4. Layout of the Control Points in the Stereo Model.

L: Left airphoto R: Right airphoto  
Ü: Overlap area S: Tie point

### 2.2.4.4 Absolute Orientation

The absolute orientation finally permits the fitting of the parallax free stereo model into the kilometer-coordinate system of the national map by utilizing ground control points, whose ground coordinates (from a map) and image coordinates (from an aerial photograph) are known. In the absolute oriented stereo model it is possible to give the x-, y-, and z-coordinates for any point.

Triangulation points or spot height from the national map 1:25,000 are used as ground control points for the absolute orientation. In the NFI1 the x- and y- coordinates were measured at the digitizing table. The value of the respective elevation information from the map was accepted for the z- coordinate. The measurement error for the x- and y- coordinates of the ground control points in the NFI1 amount to about 2.5 m (BRASSEL, oral communication). In the NFI2 new ground control points were measured from the map with the help of a line glass, so that the measuring error had about the same magnitude.

Reference points are exactly defined points from prominent objects, e.g., the north corner of a house whose three dimensional coordinates are usually determined from an absolute oriented stereo model. They should be clearly identifiable in the aerial photograph or on the map as well as on the ground. A reference point, apart from the x-, y-, and z- coordinates, consists of a description of the reference point and, depending on the type of reference point, the appropriate

description of the direction. Reference points assist the field survey team as potential starting points using measurements to locate the sample plot center. The measurement of reference points is described in detail in Chapter 2.2.6.4.

An absolute orientation has to be based on at least four ground control points if it is important to know how accurate the orientation has been. KRAUS (1990) recommends using six to eight ground control points if the precision of an absolute orientation is required to be even more accurate.

In the NFI at least six ground control points were used. However, for most of the regions, with the exception of remote areas in the mountains, about fifteen to twenty ground control points per stereo model were available from the data bank. If it turned out that fewer than six were suitable, new ground control points were measured from the national map. If possible, those ground control points and reference points were used for the absolute orientation, which were already used in the NFI1. The intent in doing this was to achieve a reconstruction of the position of the sample plot centers as closely as possible to the position they were measured in the NFI1. This also includes the position error at that time. Consequently, only the height measurements were corrected for the reference points, while the x/y- coordinate measurements were retained. If the residuals of the reference point coordinates in the x- and y- direction were too high, the control points in the stereo model were repositioned. The residuals of the x- and y- coordinates and the residual of the z- coordinate for each point were allowed to be only  $\pm 2.5$  m and  $\pm 1.0$  m respectively.

### 2.2.5 Forest Definition for the Forest/Non-Forest Decision

The discrimination of forest and non-forest areas in aerial photographs requires an unambiguous reproducible forest definition. MAHRER (pp. 40, EAFV 1988) describes the forest definition used in the NFI in the following way: “With the NFI forest definition, the aspect of a stocking is evaluated by the following stand criteria that can be measured in the aerial photograph: width, crown coverage and dominant stand height.”

The NFI2 adopted the forest definition without any changes from the NFI1. It is the most important basis for the thematic airphoto interpretation and is therefore described here (STIERLIN *et al.* 1994). Figure 5 shows the critical thresholds of the stand attributes which are used to reach the forest/non-forest decision.

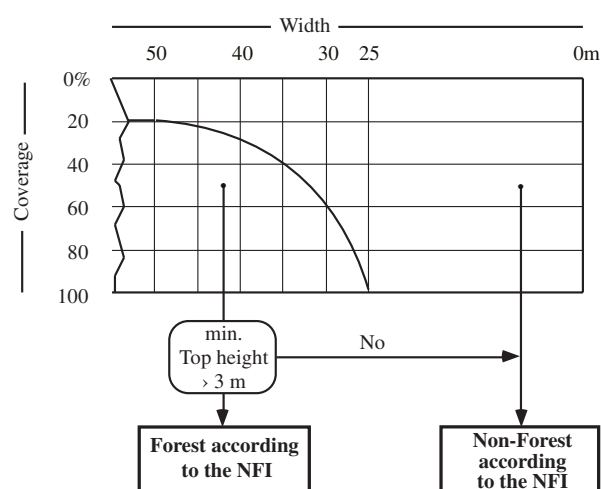


Figure 5. Forest Definition According to NFI.

- **Width:** The width of the stocked part of the interpretation area is at least 25 m. The shortest distance across the sample plot center is measured between one forest boundary line to another forest boundary line. The forest boundary line separates the forest area from the non-forest area. It encompasses all stocking elements. (Stocking elements are defined as trees and shrubs which, according to the NFI tree species list, are at least 3 m high and less than 25 m apart.)
- **Crown coverage:** The crown coverage of the stocked part of the interpretation area has to be larger than or equal to 20%. (Exceptions to this rule include: afforestation, regeneration, burned, cut, or storm damaged areas.)
- **Dominant stand height:** The stocking has to have a dominant stand height of 3 m. (Exceptions to this rule include: afforestation, regeneration, burned, cut, or storm damaged areas as well as shrub forest consisting of dwarf pine (*Pinus mugo prostata*) and alpine alder (*Alnus viridis*).

For positive forest decisions the following conditions apply: The minimum width is 25 m with a crown coverage of 100% and the required dominant stand height. With increasing width the minimum crown coverage is allowed to decrease. The smallest acceptable threshold for the crown coverage is 20% at a minimum width of 50 m.

MAHRER (1976) gives the following considerations as arguments that led to the choice of exactly these discrimination criteria for the NFI forest definition:

- When the threshold standard for the criteria of the forest definition was established, close attention was paid so that areas designated as “forest” had a forest character.
- The chosen minimum width of 25 m corresponds to approximately the length of one tree. Individual trees in a row or hedges can therefore not be designated as forest.
- The crown coverage (the ratio of the crown projection area under the canopy to the total area) must amount to at least 0.2. A crown diameter of 12 m corresponds to an average tree distance of 25 m. This in turn implies approximately one tree length. Individual stocking elements still influence each other. They are part of a larger collective of woody plant species that is perceived as “forest.”
- For the minimum required dominant tree height of 3 m an extensive inclusion of forest area was assumed. Exceptions are the alpine alder and dwarf pine stands, as well as the above mentioned special cases.

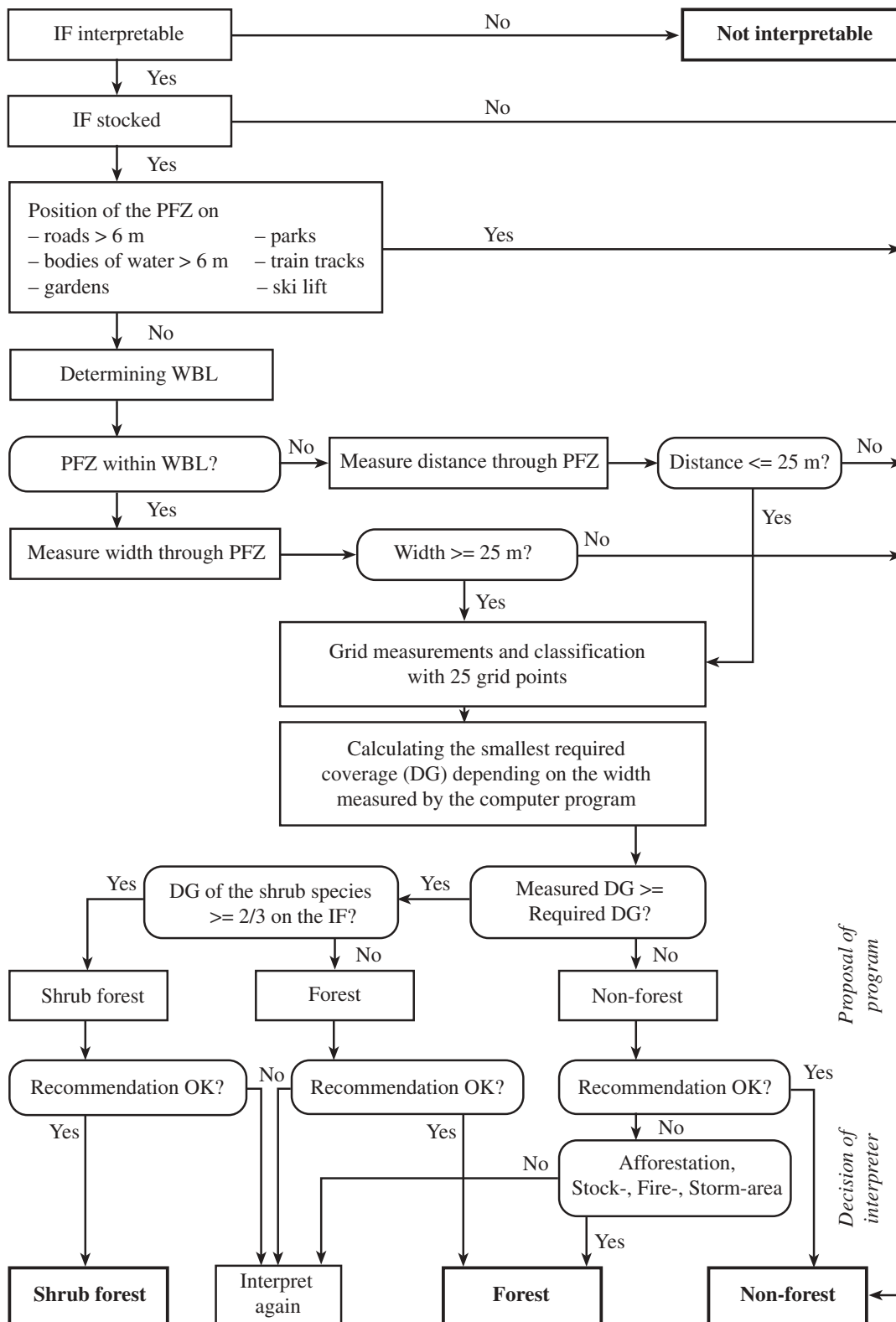
## 2.2.6 Measurements in the Stereo Model

A NFI sample plot consists of two concentric circular plots of 200 m<sup>2</sup> and 500 m<sup>2</sup> within a square interpretation area with a side length of 50 m. For the airphoto interpretation, all measurements and interpretations – apart from recording stand borders and forest edges – refer to this square interpretation area. The circular areas are only used for the terrestrial survey of the tree data.

Building upon the standard software (LEICA 1991) for the analytical plotter, a menu controlled interpretation program was developed for the airphoto interpretation. This program takes the interpreter sequentially through the individual measurements and interpretations. The sample plots of the terrestrial sample grid were interpreted using this program. (To compare the definition of sample grids in the NFI2, see Chapter 2.1 “Inventory Concept NFI2.”) For the analysis of the interpretation area in the 0.5-km-grid for which no field survey was conducted, a simplified program version was used. The differences in the program versions are specified in Chapter 2.2.7.

### 2.2.6.1 Forest/Non-Forest Decision

The aerial photo sample plots that are within a stereo model are dealt with one after the other within the interpretation program. Thanks to the absolute orientation, the floating mark of the analytical plotter automatically moves to the position with the coordinates of the first sample plot center in the chosen sector. Figure 6 gives an overview over all measurements and interpretations that lead to the forest/non-forest decision.



IF: Interpretation area  
 WBL: Forest boundary line  
 PFZ: Sample plot center  
 DG: Crown cover

Figure 6. Flow Chart of the Forest/Non-Forest Decision.

The airphoto interpretation begins with the measurements and interpretations for the forest/non-forest decision. For unmistakable non-forest samples, the interpreter can skip the measurements in the forest (distance and width) and continue with the measurements of the stocking outside the forested area (Chapter 2.2.6.5). If these stockings are missing, only the elevation of the sample plot center is measured and the next aerial photo sample is used. In all other cases the interpreter determines the forest boundary line.

The forest boundary line is clearly visible for the majority of the stands. If the canopy cover is low and the stand has larger openings or turns into a sparsely stocked stand, the determination of the forest boundary line becomes time consuming and demanding. In this case the distance of each individual stocking element (STIERLIN ET AL. 1994) to all its neighbors has to be measured, while considering at the same time the minimum required dominant stand height. Such stands can often be seen in regions near the timberline.

If the course of the forest boundary line is determined, the interpreter specifies the position of the sample plot center relative to the stocked area. If this is **outside** of the forest boundary line (e.g., in the case of forest edge indentation into a field or a meadow), the **distance** between elements is measured. If the sample plot center is **inside** of the forest boundary line, the **width** is measured in a next step.

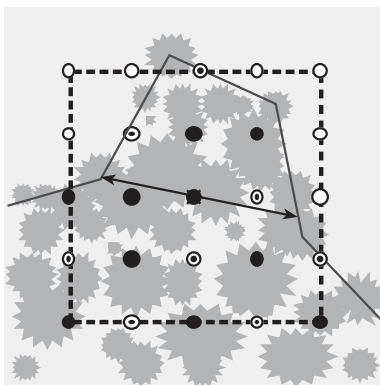
### Measurement of the Width

The width (Figure 7) of a stocking is the shortest distance from one forest boundary line to another and across the sample plot center if the sample plot center is **within** the forest boundary line (p.38, STIERLIN ET AL. 1994). The width has to be at least 25 m. For critical distances the width is measured at least three times and the arithmetic mean from these measurements is calculated. If the width criterion is fulfilled, the dot grid measurements are applied next; otherwise, the sample is non-forest.

### Measurement of the Distance

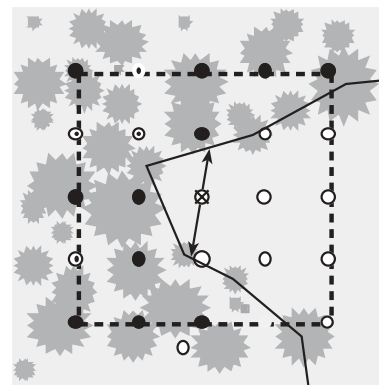
The distance (Figure 7) is the shortest distance from one forest boundary line to another and across the sample plot center if the sample plot center is **outside** of the forest boundary line (p.39, STIERLIN ET AL. 1994). If this distance is less than 25 m, it is possible that this represents a forest sample, and the dot grid measurements are continued in order to determine the crown coverage. Otherwise, this is a non-forest sample.

Position of the sample plot center  
within the forest boundary line



Width = 40 meters  
Crown cover = 56%

Position of the sample plot center  
outside of the forest boundary line



Distance = 23 meters  
Crown cover = 69%

--- Interpretation area of 50 x 50 meters  
x Sample plot center (PFZ)  
~ Forest boundary line (WBL)  
↔ Width (B), and Distance (A)  
○ Grid points outside forest boundary line

Determination of the crown cover (DG) with:  
⊙ Grid points on the forest floor  
● Grid points in tree crown

Figure 7.  
Measuring the  
width of the  
stocking and  
distance of the  
forest boundary  
line in the aerial  
photograph.

### Dot Grid Measurement

The attributes “crown coverage” and “dominant stand height” needed for the forest/non-forest decision are estimated with the help of dot grid measurements. This encompasses the measurement on 25 dot grid points (see Figure 7), which are distributed over the interpretation area of 50 m x 50 m in a grid with a mesh width of 12.5 m. The midpoint of the grid coincides with the sample plot center.

The interpretation program moves the floating mark successively to all 25 positions of the dot grid points. The interpreter measures the height of the respective object at that point (see also measurements at corner height of an interpretation area) and classifies each dot grid point into one of eight classes (Table 1). The following classes are distinguished accordingly:

Table 1. Forest and Non-Forest Classes.

| Classes                                  | Forest/Non-Forest Decision according to NFI |
|--|---|
| Non-Forest                               | Non-Forest                                  |
| Forest road with maximum width of 6 m    | ...   |
| Ground stockable                         |   |
| Ground not stockable (e.g., rock, scree) | Forest                                      |
| Conifer                                  |   |
| Broadleaf tree                           |   |
| Larch                                    |   |
| Shrub                                    | Shrub forest                                |

For the classes with stockings (“conifer,” “broadleaf tree,” “larch,” and “shrub”), the minimum dominant tree height of 3 m generally applies. The only exception is the class “shrub” for which the shrub species “dwarf pine” and “alpine alder” do not have to fulfill this requirement. Trees and other shrub species that are smaller than 3 m in height are classified as the “ground stockable” class. For temporarily unstocked areas, special regulations apply. (See also program recommendation and interpretation decision.)

From the dot grid measurements the attributes “crown coverage” and “stand profile height” are derived:

The **crown coverage** is calculated from the proportional part of the dot grid points with stocking on that part of the interpretation area which is within the forest boundary line and thus fulfills the width criterion (see Figure 7). Dot grid points that fall into the class “non-forest” are not considered in determining the crown coverage.

The **stand profile height** is the same as the mean object height of all dot grid points, which are within the forest boundary line of an aerial photo sample plot. This should not be confused with the tree height or the average dominant stand height (Chapter 2.2.6.2). The stand profile height takes on high values if the entire interpretation area consists of a compact and complete stocked stand with high trees. It is used as a stratifying variable for the growing stock determination.

### Program Recommendation and Interpretation Decision

Based on the measurements of width and crown coverage, the interpretation program gives the interpreter a recommendation: forest, non-forest, or shrub forest. The interpreter can accept or reject the recommendation. Usually the recommendation is accepted. Nevertheless, there are cases in which the recommendation has to be rejected. For example, the interpretation program will always recommend unstocked areas as “non-forest,” because the minimum required crown coverage has not been realized. By comparing this area in aerial photographs from the NFI1 or with maps, it is possible to determine if the area is only temporarily or permanently unstocked. Afforestation, regeneration, cut, burned or damaged areas, such as windthrow, snow pressure, and avalanches, are considered as “temporarily unstocked areas.” Permanently unstocked areas for example, are roads with a width between 3–6 m, creeks with a streambed width between 3–6 m, wood storage areas, and recreational facilities.

“Shrub forest” is recommended in all those cases where the criteria width and crown coverage is sufficient for a positive forest recommendation and when more than two thirds of the grid points within the forest area are classified as “shrubs.” If the recommendation shrub forest is accepted, the attributes “shrub species ” and “shrub forest type” are also assessed.

The following **shrub species** are distinguished as:

- Alpine alder (*Alnus viridis*)
- Dwarf pine (*Pinus mugo prostrata*)
- Non-identifiable shrubs

Shrub forests are arranged according to the following **shrub forest types**:

- Pure shrub forest
- Shrub forest with forest trees

### 2.2.6.2 Measurements of the Topography

Apart from measurements in the forest stands and on trees, aerial photographs are also used to measure the topography and to evaluate the ground surface of the interpretation area.

#### Elevation Measurements of the Sample Plot Center

The height of the sample plot center, according to the elevation model RIMINI (Chapter 2.7 “External Data Sources”), is taken as an initial value for the z- coordinate of the sample plot center and is recommended to the interpreter. Since this value can differ significantly from the elevation value in the absolute oriented stereo model, the recommended ground level of the sample plot center is corrected and replaced by the quantity measured in the stereo model. This measurement is done in all aerial photographs with a ground elevation of less than 2,500 m above sea level, even for obvious non-forest samples. Aerial photo samples with ground levels of 2,500 m above sea level or more are not interpreted in the aerial photographs. They are declared *a priori* as non-forest areas, since the probability is very small to detect any kind of stocking elements in these regions.

#### Corner Elevation of the Interpretation Area

Whenever possible, the elevation of the four corner points of the interpretation area are directly measured at the ground surface. Under adverse visible conditions in the stereo model and in dense stands without direct view of the ground, the corner elevation can also be measured at the dominant stand height if the elevation of the sample plot center is also measured at the dominant stand height. For this, a program option is available so that the average dominant stand height can be calculated in the proximity of the interpretation area. This is accomplished by calculating the arithmetic mean of several tree height measurements. After the last corner elevation is measured, the amount of the average dominant stand height is subtracted from all elevation measurements; that is to say, the four corner elevations as well as the sample plot center elevation.

With the help of the corner elevations and the elevation of the sample plot center, the ground surface profile of the interpretation area can be calculated. The measurements of the object’s elevation in the 25-dot-grid refer to this ground surface model. It is therefore sufficient to take only one single measurement at the highest point of an object in order to calculate the total height of this object (e.g., the tree height). A second measurement at the stem base can be omitted.

#### Slope and Aspect of the Interpretation Area

Within the interpretation area, the slope gradient can be determined by measuring the gradient vector. The ground elevation is hereby measured from two points, which are generally in the

slope line of 15 m above and 15 m below the sample plot center. From heading of the gradient vector, the interpretation program calculates the aspect of the interpretation area for forest sample plots and puts them into the classes N, NE, E, SE, S, SW, W, NW, and unknown. The interpreter can correct the aspect recommendation if necessary.

### **Relief**

Similar to the terrestrial samples, the relief of the aerial photo samples is characterized in the proximity of the interpretation area and is subdivided into seven classes:

- Plain: surface with slope <10%
- Hilltop: upper hillside, ridge
- Middle hillside: hill slope 10–70%
- Base of hill: syncline, trench
- Steep hill: hill slope >70%
- Undefined (i.e., none of the above options)
- Undefinable (i.e., not clearly visible in areas such as shade)

### **2.2.6.3 Stand Description**

Stand descriptions are suitable for collecting stratifying variables, which can be used during the analysis to estimate the strata size. One example is the stand profile height. Stand descriptions refer to the reference stand; that is the stand in which the sample plot center is located. The following attributes are a part of the stand description:

- Stand profile height
- Development stage
- Crown closure
- Stand size

### **Development Stage**

The stand attribute “development stage” is estimated in aerial photographs with the attribute “development stage AP (aerial photograph)” as well as during the field survey but is based on different criteria. The terrestrial derived “development stage” is a function of the dominant diameter at breast height (p.146, STIERLIN *et al.* 1994). This diameter cannot be measured directly in aerial photographs. Instead, it is possible to measure the object’s height and distances. The estimation of the development stage AP in aerial photographs is based on an expert opinion, which apart from the dominant stand height also takes other factors into account. These other factors are crown diameter, canopy cover density, tree species composition, production region, elevation, slope gradient, and aspect of the stand. Six different development stages are differentiated as follows:

- Young growth/thicket
- Pole wood
- Young/medium timber
- Old timber
- Mixed
- Undeterminable

Table 2 shows the relationship between the dominant stand height (in meters) and the development stage AP. The average dominant stand height at the development stage AP, young growth, pole wood, young/medium timber, and old timber are shown below.

Table 2. Development Stages (AP).

\* The average dominant stand height is not a discriminatory variable for the attribute development stage (AP). While considering the above mentioned other factors, the classification in the endlapping range is a discretionary matter of the interpreter.

| Altitudinal Zone          | Crown closure   | Development Stage (AP) |            |                      |             |
|---------------------------|-----------------|------------------------|------------|----------------------|-------------|
|                           |                 | Young Growth*          | Pole Wood* | Young/Medium Timber* | Old Timber* |
| Colline/Submontane        | Sparse – Normal | up to 8 m              | 8–20 m     |                      |             |
|                           | Crowded         | 8–12 m                 | 12–25 m    |                      |             |
|                           | All             |                        |            | 20–30 m              | from 25 m   |
| Lower and Upper Montane   | Sparse – Normal | up to 8 m              | 8–20 m     |                      |             |
|                           | Crowded         | 8–10 m                 | 10–20 m    |                      |             |
|                           | All             |                        |            | 20–30 m              | from 25 m   |
| Lower and Upper Subalpine | All             | up to 8 m              | 8–20 m     | 20–25 m              | from 25 m   |

### Crown closure

With the attribute crown closure, which is derived by way of an expert opinion, a measure of tree crown competition is found (Figure 8 to Figure 16). This attribute is quantified during the field survey, as well as during the aerial photography interpretation, according to the instructions of the NFI inventory manual (STIERLIN ET AL. 1994). In addition, mountain forest canopy cover known as “lamellar grouped” is also quantified in aerial photographs.

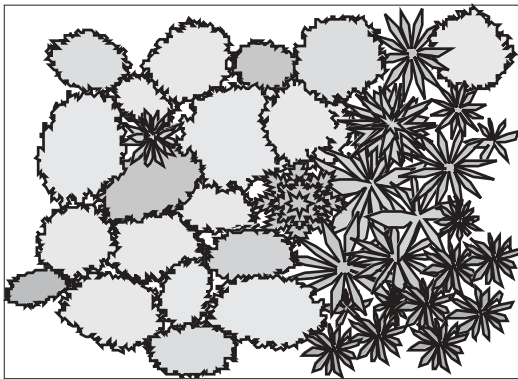


Figure 8. Crown closure crowded. The tree crowns are competing with each other. Strong contact leads to deformation and partially to asymmetric crown shapes.

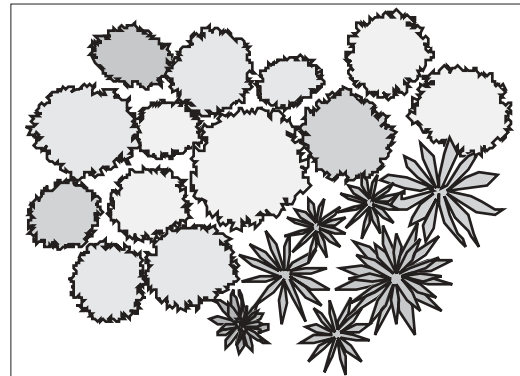


Figure 9. Crown closure normal. The tree crowns touch each other slightly but are able to develop normally and have a good shape.

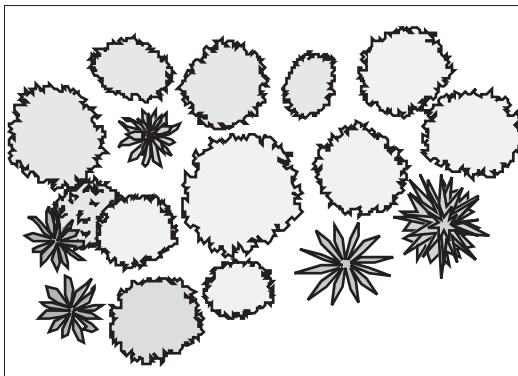


Figure 10. Crown closure open. The trees are loosely spaced for the most part without any contact. The stand has small gaps in which no other crowns move in.

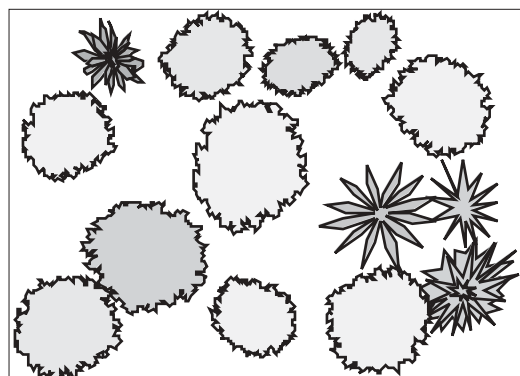


Figure 11. Crown closure open/sparse. Stands with gaps in which individual tree crowns could be added.

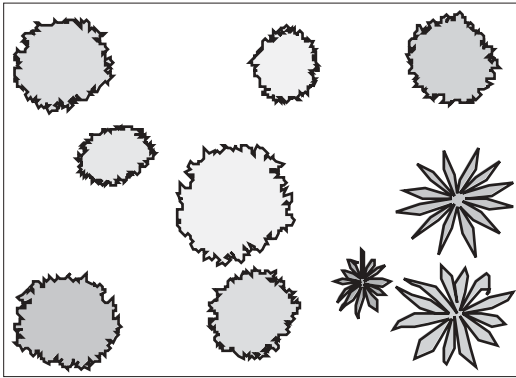


Figure 12. Crown closure sparse. Stands with large gaps in which several tree crowns would fit.

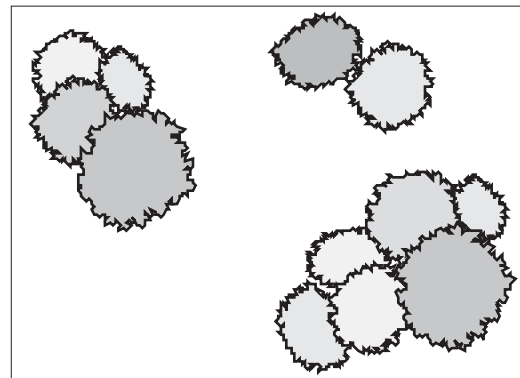


Figure 13. Crown closure grouped/crowded. Compact groups of trees with crowded crown closure. The tree crowns strongly compete with each other (e.g., clusters in the mountains).

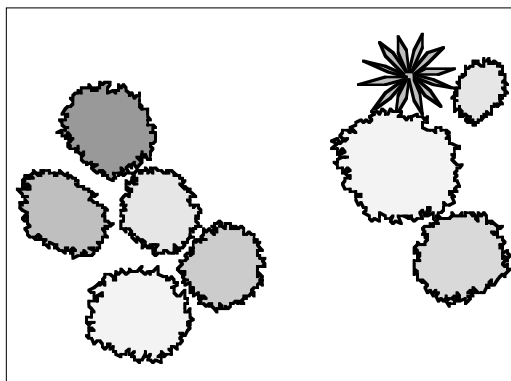


Figure 14. Crown closure grouped/normal. Small, clearly separate groups of trees with normal crown closure. The tree crowns touch each other slightly but have a good shape and develop normally.

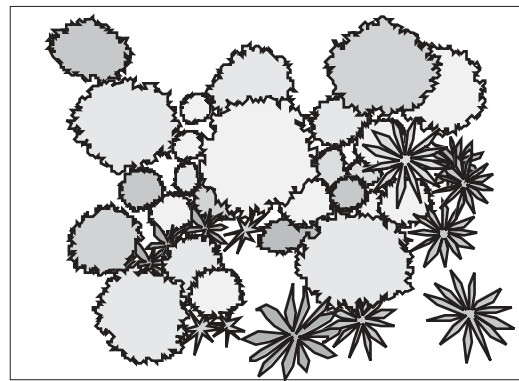
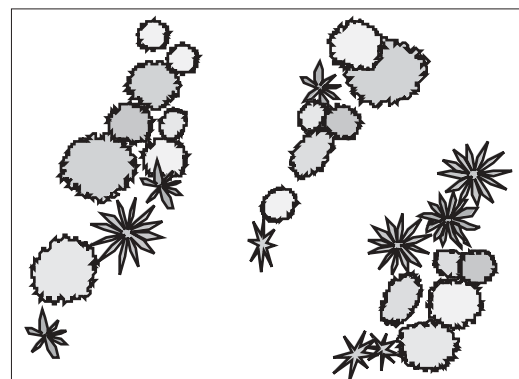


Figure 15. Crown closure complete. Stands have a layer structure. The tree crowns overlap each other (vertical competition). This can especially be seen in all-aged, selection type stands.

Figure 16. Crown closure grouped with lamellar structure. Special type on steep slopes in the mountains with staggered arranged tree groups in a “flame-like” shape, which are separated from each other by trenches (avalanches, wind, and erosion material).



### Stand size

The stand size indicates the spatial extent of the reference stand. The size does not refer to the square interpretation area with the side width of 50 m and can therefore exceed the size of the interpretation area. With the help of the floating mark, the course of the stand boundary is digitized as a closed polygon, and the size of the enclosed area is calculated. The stand boundary separates tree collectives, which differ in one or many of the following attributes: tree species composition, age, stage of development, canopy cover density, and structure.

### Stand Boundary and Forest Edge

The stand boundaries are measured if they intersect with the 500 m<sup>2</sup> circle of the sample plot area. Forest edges are always recorded in aerial photographs if the shortest distance from the sample plot center to the forest edge is less than 25 m. Both of these measurements serve as auxiliary information for the field survey team, in order to find the sample plot in the field and for the terrestrial assessment of the forest edge. These measurements permit a better estimation of the expected work expenditure and contribute to the optimization of the operations scheduling.

#### 2.2.6.4 Reference Points

An important task of the airphoto interpretation is the measurement and description of reference points, which are needed by the field survey team to locate the sample plot center. Reference points have to be clearly identified in aerial photographs as well as on the ground. Whenever possible the same reference points should be measured that were already measured during the first NFI survey. Because a long period can pass between the date when aerial photographs are taken and the date when the field survey is conducted, reference points can disappear or change position as frequently happened in the NFI2 (e.g., an intersection of two roads was reconstructed). In each aerial photo sample, two to three reference points are measured so that the field survey team can choose for themselves the most suitable one. In case the reference points are not well chosen, or cannot clearly be identified, the field survey team measures suitable reference points with the help of the line glass from the map.

In respect to position accuracy, reference points measured from the map are comparable to the ones measured in aerial photographs. However, less potential points are available than in aerial photographs, since each point has to have a measurement for the x-, y- and z- coordinates. This requirement is only fulfilled for a few points on the map, and these are usually triangulation points or spot heights. However, in the absolute oriented stereo model, the three dimensional coordinates of any arbitrary point can be measured. Therefore, any visible object becomes a potential reference point, such as a prominent tree, every visible building, a pylon of a power line, etc.

In aerial photographs, reference points can be selected that are closer to the sample plot center of interest. Due to this, the time consumption to locate the sample plot center from the reference points in the field is significantly reduced. A study from the first NFI showed that the average time to locate the sample plot center with reference points originating from aerial photography (8055 measurements) and reference points taken from the map was 22.9 minutes and 33.5 minutes respectively.

#### Reference Point Selections and Reference Point Measurements

The following objects are permissible reference points:

- |                                |  |
|--------------------------------|--|
| 1. Building                    | 10. Shaft  |
| 2. Rocks/stone                 | 11. Pole, pylon                                      |
| 3. Bridge                      | 12. Road/road intersection                           |
| 4. Road curve                  | 13. Road/trench intersection                         |
| 5. Support structure           | 14. Road/creek intersection                          |
| 6. Avalanche control structure | 15. Creek/creek intersection                         |
| 7. Conifer tree                | 16. Stand border/road intersection                   |
| 8. Broadleaf tree              | 17. Sample plot center elevation/trench intersection |
| 9. Well                        |  |

Reference points on objects with a spatial extent are complemented with the measurements of the object's elevation, and by the indication of the direction (e.g. a house with the reference point corresponding with its SW corner). The cardinal point of the object's corner at which the reference point is measured is specified relative to the center of the object.

For solitary trees the object's height is a good characteristic to distinguish them from other trees in the field.

### 2.2.6.5 Stocking Outside the Forest Area

In the NFI2, stocking outside the forest, according to the NFI definition, was quantified in all aerial photo samples of the 1.4-km-grid with a partial or complete non-forest portion on the interpretation area. The attribute “type of stocking” records whether the stockings are individual trees, woody plants, or groups of brushes, which did not fulfill the criteria of the NFI forest definition.

#### Woody Plants

If there are any woody plant formations on the interpretation area, the length and the type of the woody plants are recorded. The largest distance within a woody plant is measured and referred to as the width of the woody plant. For example, in a rectangular woody plant with the dimensions of 10 m by 20 m its length measures 22.4 m. If there are several woody plants in the same interpretation area, or if a woody plant consists of several sections, the sum of all the diameters is used.

The attribute “woody plant type” is divided into the following classes:

- Hedge/agricultural shrub
- Hedge/agricultural woody plant
- Creek/bank shrub
- Creek/bank woody plant
- Shelter-belt (artificially planted woody plant belt with protective effects, e.g., wind protection, visual protection, or noise protection belt)
- High-altitude woody plants (woody plant formations in the mountains)
- High-altitude cluster (cluster formation in the mountains)
- Woody plants in parks (woody plants without economical utilization that are often found around walkways, grassy areas, etc.)
- Forest corner (a forested area connected to a larger forest complex which does not have the minimal width of 25 m and is therefore counted as non-forest)

In the NFI, the term “shrubs” also refers to stockings, which consists of bush and shrub types (according to NFI species coding), while “woody plants” also include tree species.

#### Solitary Trees

For solitary trees on the interpretation area, the tree type is determined and the number of trees is counted.

The following tree types are distinguished:

- Forest trees
- Park trees (solitary trees in gardens or parks)
- Standard fruit trees
- Dwarf fruit trees
- Avenue trees
- Solitary shrubs
- Mixed

Knowledge about these types of important ecological parameters is interesting for two reasons: It provides information about the occurrence, type, and distribution of stocking outside of the forest according to NFI, and it serves as an input variable in international or global statistics, e.g., UN-ECE/FAO, 1990 Forest Resource Assessment. Furthermore, it allows comprehensive estimations of the total stocked area of a country and thereby simplifies the comparison of national forest area quantities, even though they are based on different forest definitions.

### 2.2.6.6 Terrestrial Clarification

Aerial photographs, which could not be clearly labeled as class “forest,” “brushwood forest,” or “non-forest“ were specially marked. In this case, the field survey team had the task of clarifying the forest/non-forest decision in the field.

It is difficult to interpret aerial photographs on steep shaded hillsides in the mountains. This is especially true in cases where nearby bright parts of rocks or snowfields cause a high contrast in aerial photographs. The development process of the aerial photographs is tailored to the needs of the Swiss Federal Office of Topography. The same process is not sufficient for the NFI measurements, especially in the already darker parts of the forest. The same is true for aerial photo samples that were covered with clouds. Nevertheless, this is rarely the case overall.

Far more often are those cases in which the measured forest width or the distance between trees is close to the critical threshold of 25 m. It is also difficult to evaluate in aerial photographs exactly where the relevant forest boundary line is located along forest edges with a high percentage of broadleaf wood, because the crowns are usually asymmetric. If the sample plot center is less than 2 m away from such a forest boundary line; it is clarified in the field.

Airphoto interpretation is also more difficult when aerial photographs are taken during the spring, since they have to be measured when the trees and stands are leafless.

Another reason for the terrestrial clarification is given when it is not possible to clearly distinguish in the aerial photograph between shrub and forest type (e.g., *Alnus viridis/Alnus incana*), leaving to speculation whether the sample is a brushwood forest or a forest. On the south side of the Alps, with its extensive coppice forest and brushwood forest, a clear separation is often impossible.

### 2.2.6.7 Combined Forest/Non-Forest Decision

The forest/non-forest decision is mainly reached in the NFI through airphoto interpretation in the first inventory phase. In some cases this is not enough, so that in the second inventory phase (the field survey) a forest/non-forest decision also has to be reached. From the combination of both decisions, the final valid decision (the so-called “combined forest/non-forest decision”) is derived.

In most cases the combined forest/non-forest decision is identical to the one derived from the aerial photographs. If the forest/non-forest decision is clarified on the ground, it then replaces the decision from the aerial photographs with one exception: If sample plots are not passable or not accessible, the decision of the airphoto interpretation prevails, since it is not possible to verify it on the ground.

A terrestrial forest/non-forest decision is performed if:

- A terrestrial clarification is requested. In this case the sample plot area is newly located.
- The field survey team finds a situation that does not fit the result from the aerial photography interpretation.

Up to eight years elapsed between the dates that aerial photographs were taken and the field survey was conducted. Due to natural or anthropogenic influences taking place during this time lapse, it was possible for significant changes to occur at the sample plot, which would have resulted in a different airphoto interpretation. Even though changes can occur when a sample plot is located next to a steep mountainside and disappears because of the erosion process, it is the exception. It is human activities, like the construction of roads or development of new regions in mountainous areas for tourist use, which are the main reasons for significant changes. At the same time there are several areas that did not meet the criteria for a positive forest/non-forest decision at the time the aerial photographs was taken but in the meantime “grew in.” In all of Switzerland, the forest area increased by 4% since the first NFI.

### 2.2.7 Analysis in the 0.5-km-grid

The analysis described in Chapter 2.2.6 refers to the terrestrial grid (1.4-km-grid or the 4.0-km-grid shifted by 0.5 km). For aerial photo samples in the 0.5-km-grid, for which no field survey was conducted, a simplified variation of the analysis software was applied that did not quantify the following attributes:

- Stand size
- Stand boundary
- Forest edge
- Reference point measurement
- Quantification of woody plants and trees outside of the forest area

### 2.2.8 Discussion and Outlook

The most important goal of the airphoto interpretation was achieved: The distinction between forest and non-forest areas for all of Switzerland with a consistent forest/non-forest decision and a given estimation error. Chapter 2.10 demonstrates that the reproducibility of the forest/non-forest is very good. Improvements are possible for attributes which are derived from expert opinions, for example stand size or lamella structure, by replacing categorical attributes with measurable quantities.

Quantification of changes is only meaningful if the same object – namely the NFI sample plots – is referenced to when discussing any changes. For the orientation of the aerial photographs in the NFI2, ground control points and reference points from the NFI1 were also employed, so that the orientation of the aerial photographs used in NFI2 approximated the one in the first NFI. Since it is not reasonable to repeat the positional error of the NFI1 in all succeeding inventories, a new method has to be found for the NFI3, to make sure that the same object as in the preceding inventories is addressed, while at the same time the true coordinates can be determined.

The importance of remote sensing for large-scale inventories is increasing. Remotely sensed data will also be one of the most important sources of data for the NFI3. At this time, it is not possible to make a final statement about the employment of remote sensing methods, since this depends decisively on the inventory goals of the NFI3 which are currently unknown.

Photogrammetry is coming into a new age. Digital photogrammetry is advancing and will most likely supersede the classical photogrammetry in the near future with its analytic plotters. Digital aerial photographs are already available today for the entire Swiss market and the Swiss Federal Office of Topography intends to update the national maps of Switzerland digitally in the future.

It is very likely that the NFI3 will employ digital data. This data will allow the employment of modern image analysis methods and can be partially automated. In addition, digital data offers the advantage of achieving reproducible and consistent results. With this an analysis over the entire area of individual attributes is within the range of possibilities.

In spite of that, it is unrealistic to assume that remotely sensed data will be analyzed completely through automation in the NFI3. Even in the future, well-trained interpreters, who are familiar with the criteria of the measured attributes from the first two national forest inventories, will still be needed. It is therefore important to maintain the continuity of the existing attributes. Improvements can be expected in areas where it is possible to replace or supplement quantities based on expert opinions, subjective interpretations, or estimations with measurable quantities.

### 2.2.9 Acknowledgments

The following people have worked successfully to make airphoto interpretation a reality in the second NFI. Michael Köhl developed the inventory methods; Robert Sutter was responsible for airphoto interpretation in general, training of the interpreters, and the photogrammetric sides of the aerial photography interpretation; and Rüdiger Jensen was responsible for programming and implementing the interpretation instructions.

### 2.2.10 Literature

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