

3.3 Prognosis and Management Scenarios

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Changes in standing volume, as well as increment and cut in the Swiss forest during the last 10 years, could be reliably estimated with the help of the two inventories NFI1 and NFI2. Volume and increment depend on the current structure of the forest (age structure, stand density, species composition). These forest structures are, among others, the result of the pursued management strategy. For the next decade, different management strategies will of course be possible. Apart from determining the changes over the last 10 years, it is also of interest to predict possible future developments, depending on different management scenarios. The existing data of the NFI1 and NFI2 are a sound basis for the prediction of medium term developments comprising 20 years.

Developments in the uniform high forest are predicted by a model which works in two decadal steps. The model is based on the data set of the two inventories NFI1 and NFI2, and on mathematical functions that were derived from these data. The increment is estimated on an individual tree basis. Forest structures which are hereby taken into consideration are updated after the first projection decade, and thus influence the growth in the second decade. External influence factors, such as climate, are not included (i.e. they are considered to be constant in this model). Given the probabilities for silvicultural treatments, the standing timber and annual increment for the year 2015, as well as the volume of harvested timber in these 20 years, is predicted.

The extrapolation of the results for the entire Swiss forest is conducted with the help of the prognosis results from the uniform high forest. Relationships between the standing timber from 1995, cut and increment from 1985–1995, as well as the development of increment and cut from 1995 to 2015 in the uniform high forest are applied to the remaining types of forest.

For the first publication of NFI results, four scenarios were calculated. Apart from the medium term potentials of harvest (equilibrium between annual increment and annual cut in 20 years), it was of interest how the standing timber and the increments developed when: 1) the management strategy of the last 10 years will not change in the next 20 years, 2) harvest is minimized and limited to maintain the protective function of the forests, or 3) the timber harvest volume exceeds today's growth substantially.

3.3.1 Models for the Uniform High Forest

In the model, the increment over a 20 years period was predicted on an individual tree basis in two decadal time steps. The extrapolated diameters of the recorded young growth are used to model ingrowth, i.e. trees that grow over the caliper threshold of 12 cm. Trees are harvested or die off with an individual probability. These operations are conducted randomly within given probabilities. The prognosis results are the average values of ten simulation runs. The model starts from the state of the forest in the year 1995 and proceeds in the following way (Figure 1):

I. Extracting Raw Data from the Data Base

The raw data consists of stand, site, and individual tree attributes in the uniform high forest that were recorded on the terrestrial sample plots. The preliminary limitation to the uniform high forest was necessary, since the mechanisms are easier to reproduce for this type of forest and developments can be more easily verified than for other forest types.

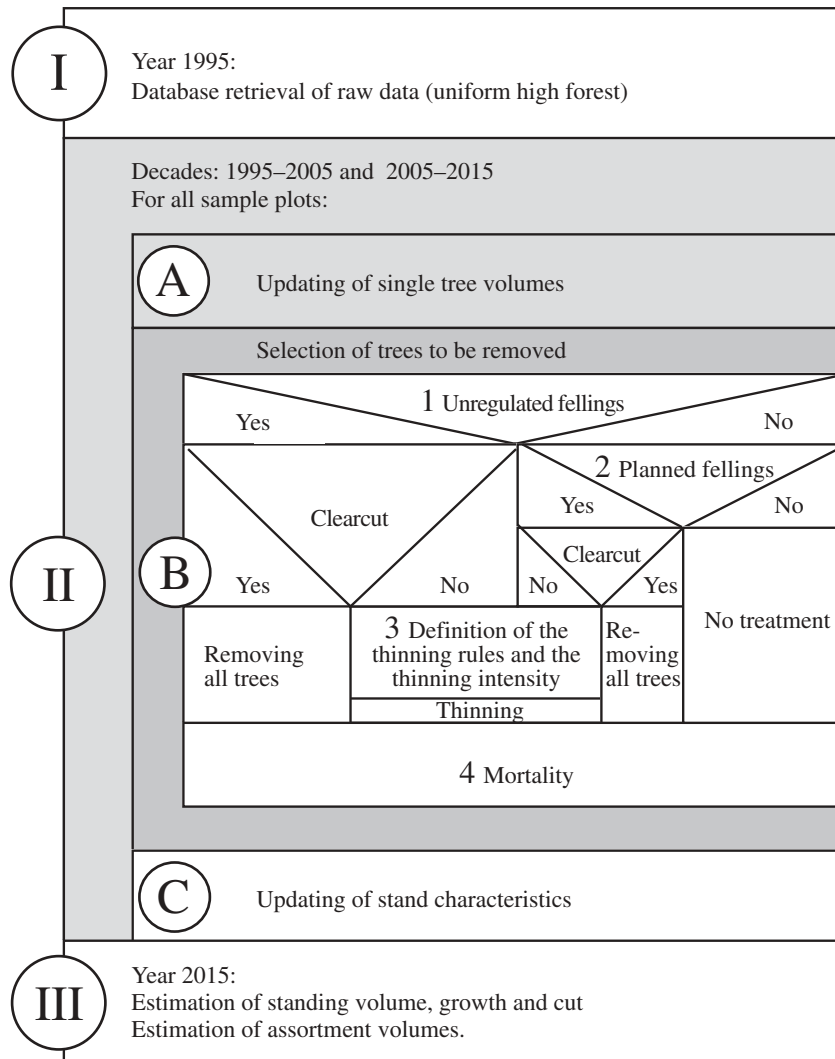


Figure 1. Flow-chart of the prognosis model.

II. Updating Individual Tree Volumes, Selection of Trees to be Removed and Updating the Stand Characteristics

A) Updating Individual Tree Volumes

The diameter growth of all of the surviving trees (Chapter 3.2.5) with a DBH > 12 cm (date t_j), and the surviving young growth trees in the young growth class 5–7 were predicted according to equation 1–3 with the increment function for the basal area as described in Chapter 3.2.2.5, Equation 15.

$$\Delta ba_i(t_j) = f(d_{1.3,i}(t_j), BAL, BASFPH, \dots) \quad (\text{See Equation 15, Chapter 3.2.2.5}) \quad (1)$$

$$ba_i(t_{j+1}) = ba_i(t_j) + \Delta ba_i(t_j) \quad (2)$$

$$d_{1.3,i}(t_{j+1}) = \frac{2}{\pi} \sqrt{ba_i(t_{j+1})} \quad (3)$$

$$v_i(t_{j+1}) = f(d_{1.3,i}, GWL, \dots) \quad (\text{See Equation 12, Chapter 3.2.2.2}) \quad (4)$$

where

ba_i : Basal area of an individual tree

v_i : Tariff volume (stem wood over bark) of an individual tree (determined for trees with a $d_{1.3} \geq 12$ cm)

t_j, t_{j+1} : Beginning and end of a 10 year growth period

Each tree dies off with a certain probability either through natural mortality or through utilization. The mortality rate ($mort_{JW}$) for the young growth is predicted by comparing the number of actual ingrowth trees in the second NFI with the trees which were assessed in the first NFI and would, theoretically, have grown in according to equations 1–3. The mortality rate is assumed to be constant. The mortality of the trees with a $d_{1,3} > 12$ cm ($mort(d_{1,3,i})$) is discussed in more detail in part B.

The numbers of trees ($N_{>12}$, $N_{>35}$) are given by the Equations 4 and 6.

$$N_{>12}(t_{j+1}) = \sum_{k|12 < d_{1,3,k}(t_{j+1}) < 35} (1 - mort(d_{1,3,k}(t_j)) + ingrowth(t_{j+1})) \quad (5)$$

$$\text{where } ingrowth(t_{j+1}) = \sum_{k|12 - \Delta d_{1,3,k}(t_j) < d_{1,3,k}(t_j) < 12} (1 - mort_{JW}) \quad (6)$$

$$N_{>35}(t_{j+1}) = \sum_{k|35 < d_{1,3,k}(t_{j+1})} (1 - mort(d_{1,3,k}(t_j)) + ongrowth(t_{j+1})) \quad (7)$$

$$\text{where } ongrowth(t_{j+1}) = \alpha \cdot \sum_{k|35 < d_{1,3,k}(t_{j+1})} (1 - mort(d_{1,3,k}(t_{j+1}))) \quad (8)$$

Ingrowth: Young growth trees that grew over the threshold of 12 cm within one period
 Ongrowth: Trees in the outer sample plot ring that grew over the caliper threshold of 35 cm (see Chapter 3.2.5)
 α : Ongrowth rate

Which of the young growth trees can grow over the threshold of 12 cm within 10 years (ingrowth, Equation 6) is determined with the growth equation (Equation 1–3). The young growth plants of the class 5, 6, and 7 of the second NFI survey (STIERLIN *et al.* 1994) are considered as the potential ingrowth up to the year 2015. The plants of the lower classes cannot reach a DBH of 12 cm during the simulation period.

The number of ongrowth trees (ingrowth over the caliper threshold of 35 cm, see Chapter 3.2.5) are calculated as proportions α of all surviving trees with a $d_{1,3} > 35$ cm (Equation 8). These rates are determined empirically with the help of the NFI data.

In the growth model, the basal area on a sample plot (BASFPH) and the competition variable BAL (i.e. sum of the basal area of all trees on a plot that are larger than the subject tree, see Chapter 3.2.2.5) have a derogating effect on the growth: The denser a stand, the higher the competition between the trees, and thus, the smaller the individual tree growth. Conversely, thinning, which reduces the competition pressure, is able to stimulate growth.

B) Selecting Cut and Mortality

1. Probability for Unregulated Fellings

In the first step those sample plots are selected at random, on which some event will cause unregulated fellings within the next 10 years. Within a stratum (A) unregulated fellings (Z) occur with probability $P(Z | A)$ (i.e., $P(Z | A)$ is the probability that the sample plot belongs to stratum A and that unregulated fellings takes place). These unregulated fellings are either a clearcut on the plot (ra; with a probability of occurrence P_{ra}) or a removal of individual trees (df; with a probability of occurrence P_{df}).

$$P_{Urs}(Z | A) = P_{ra,Urs}(Z | A) + P_{df,Urs}(Z | A)$$

where

Urs: Reason for unregulated fellings (e.g. windfall, insect infestation)

Stratum A defined by: production region, ownership, species composition

2. Probability for planned fellings

A planned silvicultural treatment (N) within a stratum (B) can occur on a sample plot on which no unregulated fellings are conducted. The probability for this is $P(N | B \setminus U)$, where U means the sample plots on which unregulated fellings are conducted within a stratum B. A planned felling can either be a clearcut (ra) or a thinning (df).

$$P(N | (B \setminus U)) = P_{ra}(N | (B \setminus U)) + P_{df}(N | (B \setminus U))$$

Stratum B defined by: production region, ownership, d_{dom} , harvesting method, site quality (GWL), expenditure for timber harvest, date of last treatment

3. Performing of thinnings

The thinning intensity (f_s) is defined separately for the trees of the upper layer and the remaining trees in the stratum S, and represents the proportions of trees to be cut. The type of thinning was formulated according to the following rule which was established based on the removals between the first and second NFI: The diameter distribution of the initial stands ($P(A_s, d)$) as well as the removed trees ($P(C_s, d)$) in the strata (S) were described by a Weibull distribution (KAUFMANN 1990). The probability that a tree with a certain diameter d from a given initial

distribution is removed, is $\frac{P(C_s, d)}{P(A_s, d)} \cdot f_s$ for the strata S, which are defined by:

production region, ownership category, unregulated felling (yes/no), stage of development, the storey that an individual tree belongs to (upper storey, not upper storey).

Figure 2 shows the diameter distribution of the upper storey trees of the initial stand $P(A, d)$, of the removals $P(C, d)$, and the selection probability $\frac{P(C, d)}{P(A, d)} \cdot f$ for development stage

“medium timber” in the public forest of the Plateau. This selection probability is the probability that a tree is cut during thinning.

4. Natural Mortality

Natural mortality occurs on sample plots without any treatment within a inventory interval. The probabilities for this are empirical frequencies, which were determined with the help of NFI data set. They are defined by production region, stage of development, and the layer an individual tree belongs to.

The probabilities established in steps 1–4 are used to extrapolate the “business as usual” scenario. For other scenarios, the removals are selected with the same procedure, but with modified selection probabilities (see Chapter 3.3.2).

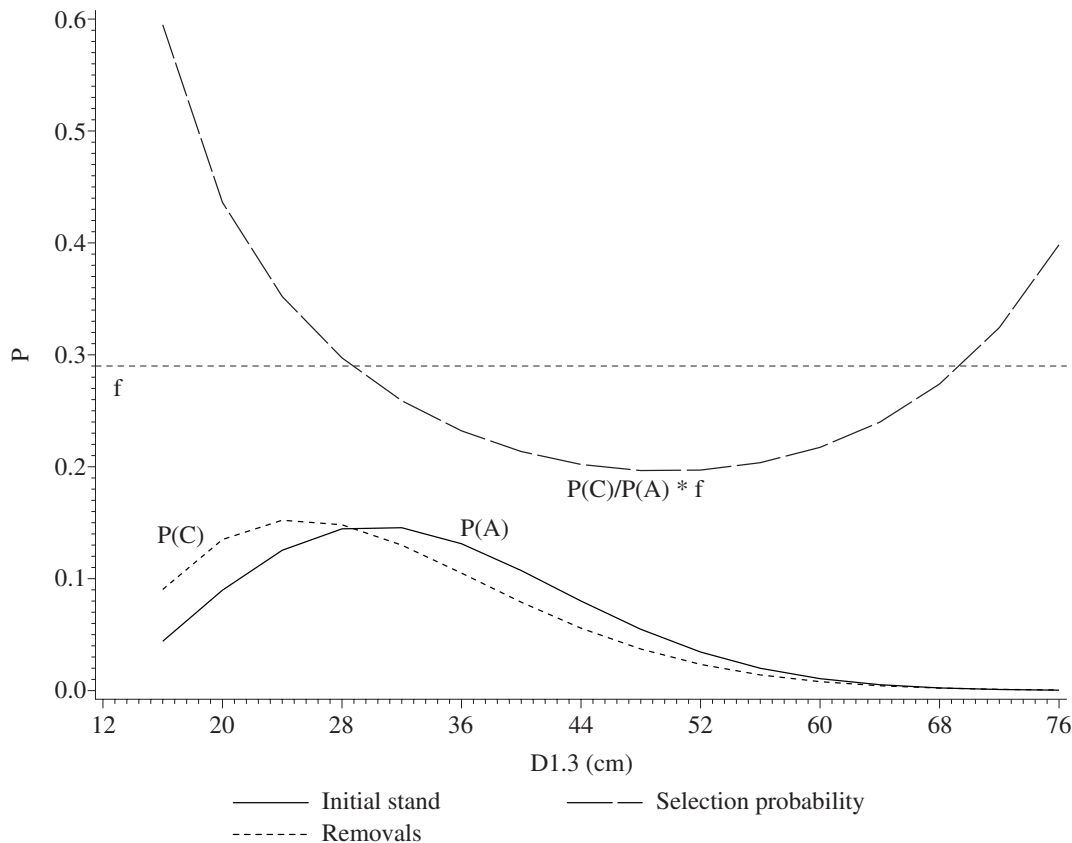


Figure 2. Diameter distribution of the initial stand ($P(A)$); diameter distribution of the removals ($P(C)$); thinning intensity (f) and selection probability ($P(C)/P(A) * f$) with which trees are selected from the initial stand A in order to obtain distribution C.

C) Updating the Stand Characteristics

Stand characteristics that are used as explanatory variables in the prediction of standing timber and increment (Chapter 3.2.2.2, Equation 12 and Chapter 3.2.2.5, Equation 15, Appendix: variable documentation), or that have an influence on the selection probability of the removals are updated after the first decade, so that the predictions in the second decade refer to changed stand conditions. For example, the d_{dom} updated after the first decade has an influence on the standing timber estimation in the subsequent decade (change of tariff volume). With the help of the d_{dom} , the stage of development, which is used to establish the selection probabilities of the removals, is also updated.

The stage of development is used in the model as a stratifying variable. A correct extrapolation of this variable is therefore necessary. The stage of development in the NFI was assessed with the help of an arbitrary estimated d_{dom} of a stand. In the scenario model, the development stage is established using a d_{dom} , which is calculated with the help of measured tree diameters. There exist random and systematic differences between the development stages that were defined in these two different ways. These differences are reproduced in the model after quantifying the errors with the help of the NFI data sets and the check assessment (see Chapters 2.9 and 4.4).

III. Determining Results

In each of the simulation runs of steps I and II, the standing volume, increment, cut and mortality per production region is estimated. The final results are the average values of 10 simulation runs. Other results as distributions of assortments or age class distributions are obtained from the last simulation run.

For the standing timber and the removals, the distribution of merchantable assortments (see Chapter 3.2.6) is of interest. In the scenario model, only the diameter at breast height is extrapolated. The information necessary to describe the stem form is therefore missing. The volume proportions of assortments are thus predicted with so called assortment tariffs. These tariffs are based on the $d_{1,3}$ and the bole volume of a tree. The NFI assortment tariffs were derived with the help of the first NFI tariff sample trees and a logistic function, as SCHMID-HAAS (1976) had recommended:

$$s_{i+} = \frac{o_{i+}}{1 + (q_i + r_i \cdot d_{1,3})^{t_i}}$$

where

- s_{i+} : Proportion of the bole volume over bark of the assortment class i and all classes of larger piece dimensions (i.e. with smaller class numbers)
- o_{i+} : Maximal achievable s_{i+}
- q_i, r_i, t_i : Parameters estimated with Gauss-Newton method (SAS 1990), (see Table 1)

The assortment volume V_{si} is estimated as the proportion of the stem volume over bark V_{ii} as follows:

$$V_{si} = V_{ii} \cdot (s_{i+} - s_{(i-1)+})$$

Figure 3 shows the assortment proportions as they were determined with the NFI1 tariff sample trees and the corresponding assortment tariff curves for long stemwood of spruce in the Plateau.

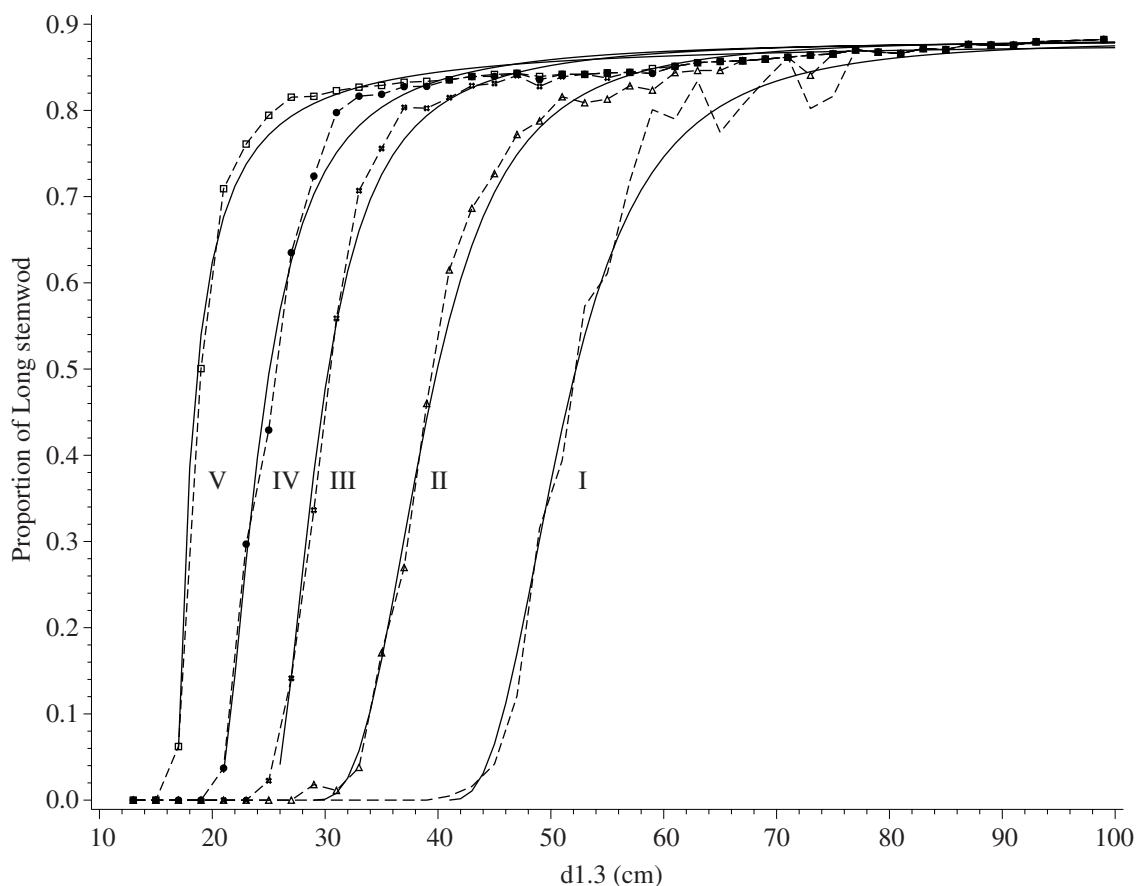


Figure 3. Proportion of short stemwood-assortments compared to the stemwood over bark, tree species spruce, observed and estimated proportions by a logistic regression function.

Table 1. Coefficientsof the conifer assortment tariffs.

		Long stemwood			
	Class	q	r	t	o
Jura under 1000 m	1	-1.1732	0.0402	-4.7146	0.87
	2	-3.067	0.0984	-2.8821	
	3	-5.3472	0.2076	-2.0944	
	4	-1.7943	0.1095	-4.1741	
	5	-5.0227	0.3194	-2.014	
Jura over 1000 m	1	-2.3825	0.0574	-3.6869	0.88
	2	-1.3536	0.0485	-3.9523	
	3	-1.3738	0.0647	-3.3738	
	4	-2.7429	0.1256	-2.2983	
	5	-2.4461	0.1592	-2.6288	
Plateau	1	-4.0292	0.0983	-2.7211	0.88
	2	-2.9016	0.1001	-2.9265	
	3	-5.43	0.2172	-1.9754	
	4	-4.9664	0.2443	-1.8207	
	5	-11.9151	0.7063	-1.1118	
Pre-Alps under 1000 m	1	-2.0369	0.0582	-4.3342	0.88
	2	-2.9706	0.101	-2.7039	
	3	-4.1924	0.1677	-1.8664	
	4	-4.7866	0.2279	-1.8793	
	5	-5.392	0.3229	-1.6034	
Pre-Alps over 1000 m	1	-3.0387	0.0707	-2.3032	0.88
	2	-4.0961	0.117	-1.6941	
	3	-3.5343	0.1309	-2.0485	
	4	-2.8032	0.1335	-2.1566	
	5	-5.392	0.3029	-1.6034	
Alps under 1000 m	1	-1.0346	0.0383	-7.7829	0.88
	2	-0.1469	0.0263	-6.9313	
	3	-2.1585	0.0914	-2.8892	
	4	-3.3876	0.1581	-2.225	
	5	-3.6924	0.2172	-1.8757	
Alps over 1000 m	1	-1.819	0.0463	-3.0043	0.87
	2	-3.398	0.0918	-2.0562	
	3	-2.2444	0.0877	-2.3446	
	4	-2.3665	0.1127	-2.2554	
	5	-2.1861	0.1457	-2.5523	
Southern Alps	1	0.3018	0.01	-10	0.87
	2	-1.8853	0.054	-1.8941	
	3	-2.6219	0.0904	-2.1266	
	4	-2.3996	0.1043	-2.5605	
	5	-2.5677	0.148	-2.3304	
		Shorter stemwood			
	Class	q	r	t	o
	Upper	-2.8363	0.0979	-2.1098	0.86
	Lower	-5.3156	0.2565	-1.2823	0.88

3.3.2 Definitions of the Scenarios for the Result Volume of the Second NFI

For the result volume of the second NFI, the following four basic scenarios were calculated which were supposed to indicate the consequences of different management scenarios. With respect to standing timber, increment, cut, mortality and age class distribution up to the year 2015, the following questions needed to be answered:

- What happens if the forest is managed as in the past (“business as usual”, Scenario 1)?
- What happens if forest management is limited to a minimum in the forests which protect a route or settlements below them from avalanches and rockfall (Scenario 2)?
- What is the order of magnitude of the medium term growth potential (Scenario 3)?
- What happens if suddenly the demand for timber increases drastically, and as a consequence more timber is harvested (Scenario 4)?

The probabilities for the removals described above are modified in the four scenarios as follows:

Scenario 1: The probabilities for planned clearcut and thinning as well as for unregulated fellings stay the same for 20 years. The date of the last silvicultural treatment is important. It reduces the probability for thinning in the second decade if there was already a silvicultural treatment in the first decade.

Scenario 2: Planned silvicultural treatments are limited to the protective forests as they are defined in NFI. These forests encompass 8% of the forested area. The probability for windfall in older coniferous spruce stands in the Plateau is increased by 50%; the remaining unregulated fellings occur with unchanged probability. No clearcut is carried out; however, thinning intensities in old stands of protective forests are augmented drastically. When thinning protective forests, up to 60% of the trees are removed in stands that are more than 200 years old and, at most, 15% of the trees are removed in younger stands. None of the other stands were touched. The mortality rate is doubled in stands where no silvicultural treatments are carried out. In this scenario, 85% of all cut trees were unregulated fellings.

Scenario 3: The probabilities for planned fellings are increased so that the current annual increment in the year 2015 equals the average annual cut of the previous 20 years. The increase of harvest was evenly distributed among clearcuts and thinning. The thinning intensity is increased by a maximum of 10% of the number of stems compared to the “business as usual” scenario. The probability for clearcuts is increased for stands older than 120 years than for younger stands. Probabilities for unregulated fellings remain unchanged.

Scenario 4: The probabilities for planned fellings are drastically increased, so that the clearcut areas and the number of the once and of the twice thinned stands increased drastically. During the thinnings, a maximum of 40% of the trees are removed.

3.3.3 Plausibility Study

Whether the model generates plausible results was studied with the help of two kinds of predictions of standing timber and increments over a 20 years period. For Scenario 1 (see Chapter 3.3.2), the standing timber and increment was predicted once starting in 1985, based on data of the first NFI (Table 2 and 3, prediction I) and once starting in 1995, based on data of the second NFI (Table 2 and 3, prediction II). With that, two prognoses for 1995 and 2005 (Table 2 and 3) were available. These results are plausible: The predictions for 1995 and the results of the second NFI, as well as both of the predictions for 2005, are nearly equal. Tables 2 and 3 show average values of ten simulation runs. The results of the simulation runs varied by 0.5–1.5% for the standing timber and the increments, for the cut by 11–18% in the Southern Alps and by 3–7% in the remaining regions.

Table 2. Volumes per hectare for the uniform high forest.

NFI: Estimation for NFI1 (1985) and NFI2 (1995).

Prognosis I: Prognosis for the year 1995 and 2005, starting in 1985 (NFI1).

Prognosis II: Prognosis for the year 2005 and 2015, starting in 1995 (NFI2).

	Jura				Plateau				Pre-Alps				Alps				Southern Alps				Switzerland			
	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015	1985	1995	2005	2015
NFI	342	373			410	434			449	481			317	340			187	220			360	387		
Prognosis I		366	395			426	454			487	518			341	339			215	253			384	406	
Prognosis II			402	435			455	471			512	539			347	352			238	283			407	428

Table 3. Increment and cut in the uniform high forest.

NFI: Estimation for NFI1 (1985) and NFI2 (1995).

Prognosis I: Prognosis for the year 1995 and 2005, starting in 1985 (NFI1).

Prognosis II: Prognosis for the year 2005 and 2015, starting in 1995 (NFI2).

	Jura		Plateau		Pre-Alps		Alps		Southern Alps		Switzerland				
	85-95	95-05	.05-15	85-95	95-05	.05-15	85-95	95-05	.05-15	85-95	95-05	.05-15			
Increment															
NFI	9.3			13.9			11.7			7.5		5.1		10.1	
Prognosis I	9.5	9		14.5	14.4		12.2	12.1	8.1	6.5	5.1	5.8	10.5	10	
Prognosis II		8.8	9		14.1	14.2		11.3	11.3	6.6	6.5	4.4	6.3	9.6	9.8
Cut															
NFI	6.4			11.6			8.4			5.5		2		7.4	
Prognosis I	6.6	5.9		12	12		7.4	8.3	5.1	6.4	2.1	1.7	7.3	7.7	
Prognosis II		5.7	6.1		11.7	12.9		7.7	8.7	5.5	5.7	2.5	1.6	7.3	7.8

3.3.4 Prediction of Standing Timber and Increment for the Entire Forest

The results for the uniform high forest obtained by model predictions were extrapolated for the entire accessible forest. The forest types “uniform high forest,” “non-uniform high forest,” and “coppice forest/coppice with standards” were distinguished.

The average cut volume (including mortality) for the uniform high forest during the period 1995–2015 compared to 1985–1995 decreases to 95% in Scenario 1, to 28% in Scenario 2, and it increases to 172% in Scenario 4. The same changes in terms of percentages were assumed for the remaining forest types. In Scenario 3, the cut for all types of forests were continuously increased until there was a balance between cut and growth in the year 2015.

The relationship between the standing timber in the year 2005 (V_{05}) on one hand and V_{95} (standing timber 1995), Gg_{85-95} (increment 1985–1995), CM_{85-95} (cut and mortality 1985–1995), and CM_{95-05} (cut and mortality 1995–2005) on the other hand are expressed with a regression model. With this model, the V_{05} for the forest type “non-uniform high forest” and “coppice forest/coppice with standards” can be estimated:

$$V_{05} = b_0 + b_1 \cdot V_{95} + b_2 \cdot Gg_{85-95} + b_3 \cdot CM_{85-95} - b_4 \cdot CM_{85-95}$$

$$b_0 : 4.942, \quad b_1 : 0.937, \quad b_2 : 0.948, \quad b_3 : 0.541, \quad b_4 : 1.305$$

It is assumed that the development of standing timber over 20 years is linear. This means that for the period 2005 to 2015, the same change is assumed as for the period 1995–2005. The increment for 2005–2015 can be calculated with $Ggi_{05-15} = V_{15} - V_{05} + CM_{05-15}$ (see page 309 HUSCH *et al.* 1972).

The extrapolation of the standing timber and increment prediction from the uniform high forest to the entire forest in this manner is preliminary. Non-uniform stands are intended to be included for continued development of the models that are planned. Assuming that the prediction procedures for the uniform high forest lead to correct results, the extrapolations with regards to the entire forest, which were calculated in this simple way, are at least in the correct order of magnitude. An extension of the prediction procedures will, however, give more precise and more reliable results.

In a new version of the model, the treatment probabilities will be determined by logistic models. The parameterization will be, therefore, substantially simplified, and the dependencies between treatment probabilities and explanatory variables will become more transparent. With this, additional scenarios will also be more easily expressed.

The medium term prediction results generated with the model do not only depend on a chosen scenario, but also on whether the growth reaction to the thinning was correctly predicted, and whether the standing timber would be unbiasedly estimated with the NFI volume tariffs in changed forest populations. The increment and tariff functions of the NFI are, strictly speaking, only valid for changes between the two inventories NFI1 and NFI2 and for the state of the forest at both inventories. Whether or not they give the correct results for the prediction period of 20 years cannot be verified with the inventory data. It is therefore planned to study the increment reaction to silvicultural treatments and the shifts in volume tariffs with the help of data from forest yield experiments.

3.3.5 Literature

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