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FORECE – A Forest Succession Model for Southern Central Europe

Felix Kienast

Environmental Sciences Division
Publication No. 2989

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ENVIRONMENTAL SCIENCES DIVISION

FORECE - A FOREST SUCCESSION MODEL FOR SOUTHERN CENTRAL EUROPE

Felix Kienast*

Environmental Sciences Division
Publication No. 2989

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

Kienast, F. 1987. FORECE - A forest succession model for Southern Central Europe. ORNL/TM-10575. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 82 pp.

A general forest succession model that simulates forest stand development for the most common site conditions in the southern part of Central Europe (with emphasis on Switzerland) is described. The model provides a useful tool for testing hypotheses about forest succession and enables the user to evaluate the impacts of natural and human disturbances on forest communities. Written in FORTRAN, it is a JABOWA-type simulator (Botkin et al. 1972) and is based on existing succession models for forests in eastern and western North America. Birth, growth, and death of 31 species of individual trees are simulated on a multitude of 1/12-ha plots. The successional characteristics of each replicate are subsequently averaged to obtain the forest development on a landscape level. Existing light in the forest stand, climatic conditions, soil properties, and other environmental factors control the growth of each individual tree. Species-specific input data such as light requirements and drought resistance were obtained from silvics information and phytosociological descriptions. Compared with previous simulators, some major modifications were made, including the incorporation of the indicator value concept of Ellenberg (1978). This approach is partially optional and is used to describe the ecophysiological behavior of the 31 different tree species incorporated in the model. As another option, common silvicultural practices may be applied. Economically or ecologically important species can be favored, and even-aged or uneven-aged forests can be anticipated. Forest development under air pollution stress can also be simulated; to this end the growth vigor of the trees included in the model can be lowered according to the sensitivity of the corresponding species to different air pollutants.

1. INTRODUCTION

The application of computer models in long-term forest dynamics studies and ecological succession analysis is increasing. Several hundred digital computer models have been developed and applied to test theories of succession and to assess environmental impacts on different forest ecosystems. In their review of modeling approaches, Shugart and West (1980) distinguished between three types of models (i.e., tree models, gap models, and forest models), depending on design, data requirements, and potential applications. According to their terminology, the forest simulator 'FORECE' (FOREsts of Central Europe) is a gap model. Characteristics of individual trees are simulated on multiple forest plots (gaps) of 1/12 ha and subsequently averaged. This concept is supported by different plant succession studies, which show that a mature forest ecosystem may be described by the average growth dynamics of a multitude of gaps (Bray 1956; Curtis 1959; Watt 1947). The plot size represents the approximate gap that occurs if a dominant tree of a closed-canopy forest dies (Shugart and West 1981). The gap concept, which aggregates the responses of different homogeneous mosaic patches through time, also allows the simulation of the spatial heterogeneity in a forest ecosystem (Shugart 1984).

The purpose of this forest simulator is to model forest development on the most common site conditions in the southern part of Central Europe, with emphasis on Switzerland. The simulator should provide a tool for testing hypotheses about forest succession and enable the user to evaluate the impacts of natural and human disturbances on forest communities. The simulator is based on previous models of Botkin et al. (1972) (JABOWA), Dale and Hemstrom (1984) (CLIMAX), Pastor and Post (1985), and Shugart and West (1977) (FORET). Stand development on each modeled plot is obtained by simulating establishment, growth, and death of individual trees as stochastic processes. Forest succession is driven by extrinsic and intrinsic variables of the species or the stand, respectively (Fig. 1, Solomon 1986). Extrinsic variables to the stand are summer warmth,

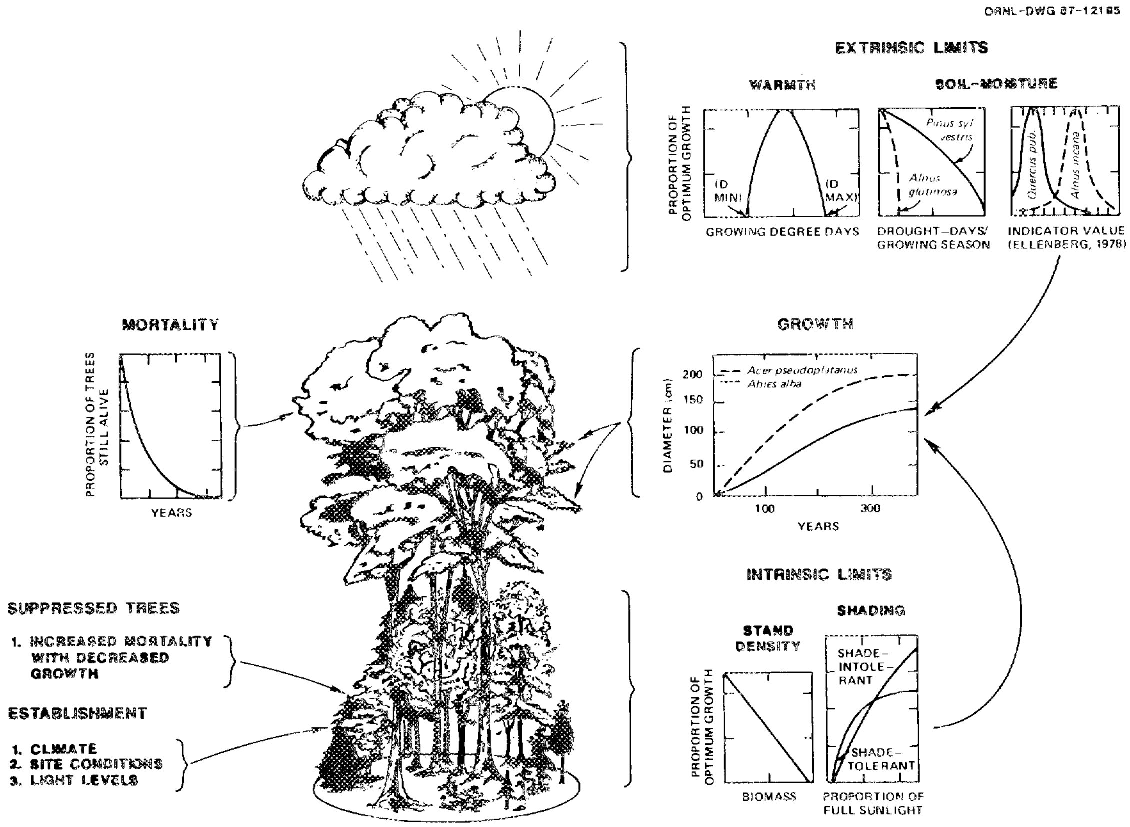

Fig. 1. Schematic representation of the factors controlling growth on a unit plot (1/12 ha) of the FORECE succession model. Examples of the limiting processes are given in the schematic diagrams a to g (after Solomon 1986).

spring frost, soil conditions, and browsing. Intrinsic variables to the species are maximum potential growth rate and mortality, whereas shading and crowding are intrinsic variables to the stand. Each model starts with a randomly selected cohort of seedlings in a gap to simulate tree establishment. Unfavorable environmental factors and site conditions control the exclusion of species from the seed pool. The growth of each individual tree is simulated by decreasing its maximum potential growth rate (Fig. 1e) to a less than optimal value by a variety of factors. To do so growth multipliers for each limiting factor are calculated to express the proportion of optimum growth under the corresponding conditions. The growth equation for optimum diameter growth of a tree is based on the assumption that the biomass increment in 1 year is proportional to the amount of sunlight the leaves receive multiplied by a factor for maintaining living tissue already present (Botkin et al. 1972). Death of individual trees is determined by using of a mortality function that allows only 1% of all trees to reach the maximum physiological age. Also, trees are 'killed' if they are growing slower than some minimum rate specified by the user. Individual species data such as light, soil moisture requirements, and maximum age were derived from silvics information and phytosociological vegetation descriptions (Amann 1954; Bernatzky 1978; Ellenberg 1978; Mitscherlich 1970).

This report is primarily a users manual and consists of a full description of the simulation program, including detailed information about the formulas used. One example run is discussed in detail to give the reader an idea about the potential of this model. A full listing of the FORTRAN code can be found on microfiche in Appendix A.

2. PROGRAM STRUCTURE

The entire model is managed by the MAIN program, which involves different subroutines, as displayed in Fig. 2. Subroutine INPUT reads individual species data, environmental data of the site type to be simulated, program commands, and scenario information. A simulation can be performed for as many replicates (plots) and years as specified by the user. The model is designed to start with bare plots or with a given species composition, which is provided in the subroutine PLOTIN. Subroutines TEMPE, MOIST, and LINIT simulate the climatic conditions and the soil moisture properties of the stands in any given year of the succession. Monthly temperature and precipitation data are calculated randomly around a given mean temperature. Available soil moisture is calculated using a simple soil water model described by Pastor and Post (1985). Climatic conditions and soil moisture status are subsequently transformed into the appropriate growth multipliers (subroutine GMULT).

Subroutine BIRTH simulates the natural establishment of trees as well as human planting activities. The available seed pool depends on the actual environmental conditions, forest composition, and human planting. Parameters controlling the seedling rates include frost, degree days tolerance, winter temperature, browsing, and available light at the forest floor. Shading between trees is calculated by determining the leaf area each tree is generating along a vertical profile through the forest canopy. The possibility of sprouting from roots when aboveground parts are lost is simulated in subroutine SPROUT.

Subroutine GROW calculates the yearly growth increment of each tree included in the model. Initially, some additional growth multipliers are obtained, for example, shading of each tree within the canopy and competition for nutrients expressed in a crowding factor. Subsequently, each tree's optimum growth at its respective diameter at breast height (dbh) is reduced by the growth multiplier that is

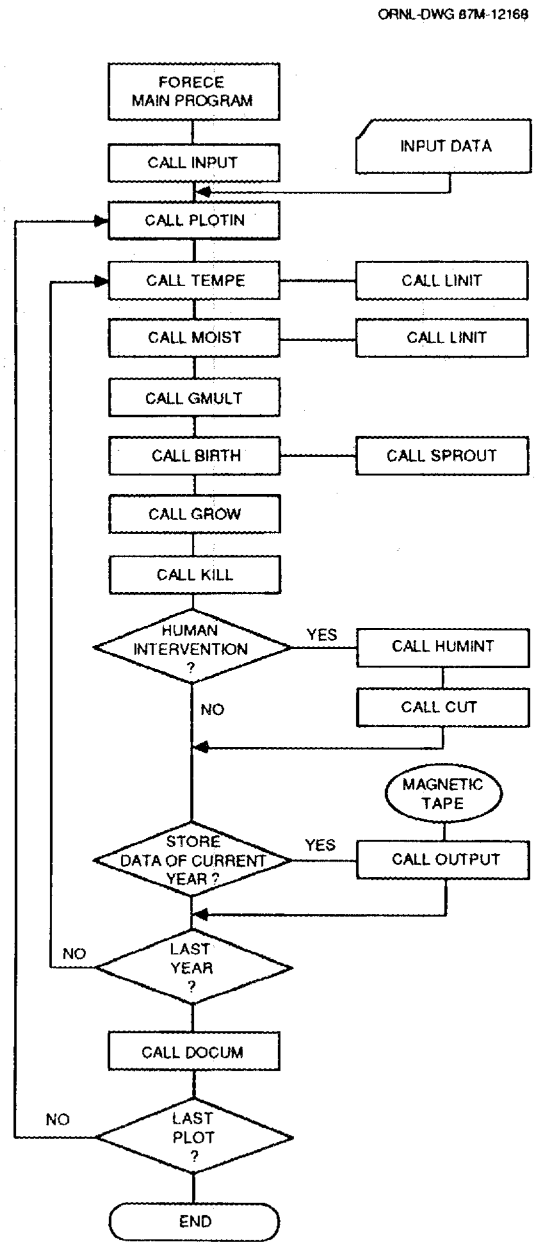

Fig. 2. Flow chart of the forest simulator FORECE with information about the subroutines involved.

limiting tree growth most strongly (Liebig's law of the minimum). Subroutine GROW also calculates reduced growth resulting from air pollution influences.

Subroutine KILL randomly selects trees for death based on either an age-dependent or an age-independent mortality criterion. Forest management influences are simulated in subroutine HUMINT and CUT. Based on common Swiss forest practices, even-aged and uneven-aged stands may be anticipated. Economically or ecologically desirable species can be favored by means of selective cutting or planting. The remaining subroutines (OUTPUT, DOCUM) are used for data management. OUTPUT stores yearly obtained data of biomass, tree diameter, etc., on tape. DOCUM is a documentation routine. It provides information about growth limiting factors for each plot and species and calculates forest composition at the end of each simulation.

3. PROGRAM CODE

This program code is based on gap models described by Dale and Hemstrom (1984), Pastor and Post (1985), and Shugart and West (1977). It is not the intent of this report to completely describe the context of these models; only new and greatly modified subroutines will be discussed in detail. The reader will find a complete listing of the FORTRAN code in Appendix A (microfiche). The code is written in a basic FORTRAN language without special software requirements to facilitate the adaptation of the simulator to different computer systems. In its present form the program runs on an IBM-3033 computer. The random number generator used is a system routine that provides normally and uniformly distributed random numbers. Data are written on two tapes that must be available during the simulation process.

3.1 MAIN PROGRAM

The MAIN program initializes most common blocks and documentation arrays to manage the parameter transfer among subroutines (Table 1). The common block parameters are listed in Table 2 and described in detail in Tables 3a and b. The DO-60 loop manages the forest simulation for each plot and is repeated for as many times as the user requests. The DO-50 loop calls subroutines TEMPE, MOIST, GMULT, BIRTH, GROW, and KILL in each year of the succession. If forest management is desired (see subroutine INPUT) subroutine HUMINT is called. The MAIN program finally calls subroutine OUTPUT to write the current succession data on tape. Subroutine DOCUM is called at the very last simulation year of each individual plot to document limiting factors for tree establishment and growth. Also, the forest composition of each plot is documented.

Table 1. Common blocks used in program FORECE, and communication among subroutines

Common block	Subroutine														
	MAIN	INPUT	PLOTIN	TEMPE	MOIST	GMULT	BIRTH	SPROUT	GROW	KILL	OUTPUT	LINIT	HUMINT	CUT	DOCUM
AIRPOL		*							*						
BIR		*					*								
CONST	*	*	*		*	*	*	*	*	*	*		*	*	
COUNT	*	*			*		*	*	*	*	*			*	
CUTS							*			*			*	*	
CUT1													*	*	
DEAD	*		*				*	*	*	*	*			*	
DOCU	*						*						*	*	*
DO1											*				*
FOREST	*		*				*	*	*	*	*		*	*	*
GMLT	*					*	*	*	*	*	*				
GROWD	*								*						*
HUMAN	*	*					*						*		
INTERP	*	*										*			
LINEAR	*	*										*			
OPT	*	*				*	*		*	*	*		*		*
PARAM1	*	*				*	*	*	*	*	*		*	*	*
PARAM2	*	*	*			*	*	*	*	*	*		*	*	
PROD	*								*	*	*				
SOILCO		*				*			*						
TEMP	*						*	*	*	*	*				
WATER	*	*		*	*	*	*	*	*		*				

Table 2. Common block parameters

Common block	Parameter
AIRPOL	AIRP
BIR	ABROW,AFROST
CONST	NSPEC,DEGD,SOILQ
COUNT	NTOT,NYEAR,KPRNT,NMAX,KLAST,NWRITE,KWRITE
CUTS	NFAVO,IFVRT,IHRVST
CUT1	MIN,NUM
DEAD	NOGRO,NTEMP
DOCU	IDOC,IDOCU,IDOCU1,IDC,IFAVDO,INFADO,IPLNDO
DO1	BAR,XLAI,ATOT,TBAR,AVGBAR
FOREST	NTREES,DBH,IAGE,KSPRT,NEWTR,SUMLA,NEW,ACHANC
GMLT	SMGF,DEGDGF
GROWD	IGRO,IGRO1,AGRO1
HUMAN	IFTYP,IDIST,IHARV,DBH1,IDBH2,IREG,IPLANT,IFAVO,IFAVOR,ISCREN, ICYC1,MPLNT,ABROW1,IDIFF,IFIRST,ALIM1,ALIM2,ALIM3,ALIM4,ARATIO, STEMDY
INTERP	IPOLAT,X
LINEAR	TSAV,VTSAV,RSAV,VRSAV
OPT	OPTION,SCENA
PARAM1	AAA,INUM,DMAX,HMAX,DEGMI,DEGMX,DEGOL,DEGOU,TEMOL,TEMOU,PRCOL, PRCOU,AGEMX,B2,B3,G1,G2,DYG,ISHAW,ISPRT,IMAM,IF,ISO2,INO2,INO3, IDRT,IFRSS,IMST2
PARAM2	AVJAN,ILIGH,ITENO,IAMPL,IMST1,IACID,INIT,ISEXM,A1,A2,C1,C2, DRANG,ASPEC1,ASPEC2
PROD	AWP
SOILCO	SOILC,SGF
TEMP	DTEMP,ITEMP
WATER	T,VT,RT,R,VR,FC,DRY,BGS,EGS,PLAT,FJ,AET,AFIX

Table 3a. Parameter list of program FORECE

Parameter	Units	Explanation
AAA		Alphanumeric species name
ABROW		Browsing switch (Y: on; N: off)
ABROW1		Automatic browsing switch for forest management
ACHANC		Multiplier for seed availability
AET	cm	Actual evapotranspiration
AFIX		Switch for identical climatic scenario in all plots (Y: on; N: off)
AFROST	°C	Temperature thresholds for frost occurance
AGEMX	years	Maximum age of each species
AIRP		Holds information about the air pollution scenario
ALIM1	cm	Lower DBH limit for forest screening (managed forests)
ALIM2	cm	Upper DBH limit for forest screening (managed forests)
ALIM3	cm	DBH limit for trees considered valuable (managed forests)
ALIM4	%	Anticipated number of harvested trees of valuable size (favorite species; uneven-aged forests)
ARATIO	%	Anticipated percentage of favored trees for each DBH class
ASPEC1		Species selection matrix (Y: participating; N: not participating)
ASPEC2		Species identification matrix (C: coniferous, D: deciduous)
AVJAN	°C	Lowest possible average January temperature for species
AWP	kg/(plot*yr)	Aboveground woody production
A1		Species-specific factor for foliage biomass equation
A2		Species-specific factor for foliage biomass equation
BAR	kg/(plot*yr)	Species biomass
BGS		Julian day of the first day of the growing season
B2		Species-specific growth scaling factor
B3		Species-specific growth scaling factor
C1		Species-specific conversion factor for dry leaf weight
C2		Species-specific factor that converts foliage biomass to leaf area
DBH	cm	Diameter of each tree at breast height
DBH1	cm	see IHARV
DEGD		Degree days for current year
DEGDGF		Degree day growth multiplier
DMAX	cm	Maximum diameter of each species
DEGMI		Degree day minimum for each species
DEGMX		Degree day maximum for each species
DEGOL		Lower limit of degree days for species dominance
DEGOU		Upper limit of degree days for species dominance
DRANG		Species-specific conversion factor for leaf biomass
DRY	cm	Soil wilting point
DYG	years	Number of years with advanced youth growth
EGS		Julian day of the last day of the growing season
FC	cm	Soil field moisture capacity
FJ	days	Total number of dry days in current year
G1	cm	Upper limit of scalar for species maximum growth
G2	cm	Lower limit of scalar for species maximum growth
HMAX	cm	Maximum height of each species
IACID		Species-specific soil pH index (1: acid; 9: alkaline)
IAGE	years	Age of each tree
IAMPL		Species-specific continentality index (1: oceanic; 9: continental)
ICYC1	years	Removal cycle for wood in managed forests
IDBH2		Even-aged forests: largest DBH class remaining after clear cut
IDIFF	trees/plot	Differences between anticip. and actual DBH distribution
IDIST	trees/plot	Anticipated DBH-distribution function for uneven-aged forests
IDRT		Drought resistance (1: very low; 5: very high)
IF		Species-specific sensitivity to fluorides (0: tolerant; 3: intolerant)
IFAVO		Number of species to be favored (managed forests)
IFAVOR		Species identification for favored species
IFIRST	years	Number of years without wood removal (managed forests)
IFRSS		Species-specific frost resistance in spring (1: very low; 5: very high)
IFTYP		Forest type aimed (managed forests)
IHARV	trees/plot	Anticipated number of trees bigger than DBH1. Threshold for harvest initialization in even-aged forests
ILIGH		Species-specific light index (1: tolerant; 9: intolerant)

Table 3b. Parameter list of program FORECE

IMAM		Species-specific browsing tendency of mammals (1: no browsing; 3: high browsing tendency)
IMST1		Soil moisture index 1 (1: very dry; 9: wet)
IMST2		Soil moisture index 2 (ibid.)
INIT		Species-specific nitrate index (1: low; 9: high)
INO2		Species-specific sensitivity to NO_2 (0: tolerant; 3: intolerant)
INO3		Species-specific sensitivity to NO_3 (0: tolerant; 3: intolerant)
INUM		Numerical species identification
IPLANT		Species and quantities of seedlings to be planted (even-aged forests)
IPOLAT		Number of break points in climate data interpolation
IREG		Method of tree establishment (managed forests)
ISCREN	years	Number of years after which forest is screened for the first time
ISEXM	years	Minimum tree age for seed production
ISHAW		Ability of each species to withstand shade (1: tolerant; 5: intolerant)
ISO2		Species-specific sensitivity to SO_2 (0: tolerant; 3: intolerant)
ISPRT		Tendency of each species to build basal sprouts (0: low; 2: high)
ITENO		Species-specific temperature index (1: cold, subalpine; 9: warm, mediterranean)
KLAST		Number of plots to be simulated
KWRITE		Output control
KPRNT	years	Output print interval
KSPRT		Indicates dead trees eligible to sprout
NEW		Indicates species eligible to sprout
NEWTR		Indicates species eligible to seed in
NMAX		Number of times subroutine OUTPUT is called per plot
NOGRO		Records trees below minimum growth for current year
NSPEC		Number of species
NTOT		Current number of trees in simulation
NTREES		Number of trees for each species
NWRITE		Output control
NYEAR	years	Total number of years in simulation
OPTION		Holds switches for different model options
PLAT	degrees N/S	Latitude of plot
PRCOL	cm	Lower annual precipitation limit for species dominance
PRCOU	cm	Upper annual precipitation limit for species dominance
R	cm	Interpolated precipitation means for current year
RSAV	cm	Precipitation means by month
RT	°C	Current monthly temperatures
SMGF		Soil moisture growth factor for each species
SCENA		Holds switches for different scenarios
SGF		Optional soil growth multiplier
SOILC		Holds optional soil conditions scenario
SOILQ	kg/plot	Maximum biomass per plot recorded in the area
STEMDY	trees/plot	Stem density for different mean DBH (even-aged forests)
SUMLA	kg/plot	Vertical distribution of leaf area in the canopy
T	°C	Interpolated mean monthly temp. for current year
TBAR	kg/ha	Biomass of current year
TEMOL	°C	Lower annual average temperature for species dominance
TEMOU	°C	Upper annual average temperature for species dominance
TSAV	°C	Temperature means by month
VR	cm	Interpol. monthly precip. standard dev. for current year
VRSAV	cm	Precipitation standard deviations by month
VT	°C	Interpol. monthly temp. standard dev. for current year
VTSAV	°C	Temperature standard deviations by month
X	years	Years in which climate changes
XLAI	m^2/m^2	Leaf area index

The following parameters are temporarily or used only for documentation: MPLNT, MIN, NTEMP, NFAVO, NUM, ITEMP, IPLNDO, IHRVST, IGRO1, IGRO, IFVRT, IFAVDO, INFADO, IDOCU1, DOCU, IDOC, IDC, DTEMP, AVGBAR, ATOT, AGRO1

3.2 SUBROUTINE INPUT

This subroutine reads run-control parameters, scenario information, and individual species data. A complete data input is documented in Tables 4, 5a through c and in Appendix A. Parameters described in Tables 3a and b are only briefly discussed.

First, INPUT reads run-control parameters and scenario information (Table 4). On line 1, the parameters 'KPRNT', 'KLAST', 'NYEAR', and 'PLOTS' are read. The parameter 'PLOTS' requests graphics plots if the switch is turned on ('Y': on; 'N': off). 'SOILQ' is the maximum recorded biomass for forests in the area. According to Swiss yield tables (Swiss Federal Institute of Forestry Research, 1967, 1969, 1983a,b), maximum stemwood volume (without branches) on managed optimum silver fir (Abies alba) sites is approximately 1000 m^3 after 150 years. By assuming a mean wood density of 0.45 g/cm^3 (15% water content, Schweiz. Forstkalender 1982), a biomass of 450 t/ha would be reached. Accounting for an additional biomass of branches and foliage between 20 and 30% of the trunk biomass (Goryschina 1974), a SOILQ value of 45,000 kg/plot (540 t/ha) seems to be reasonable for low-elevation sites. According to investigations of Leibundgut (1959), natural beech-fir forests in Yugoslavia and Czechoslovakia showed wood volumes between 800 and 1400 m^3 in their optimum phase. On line 2 of Table 4, start values for the IBM-specific random number generator are read (parameters ISEED, JSEED). On line 3, the user identifies species that are included in the model (parameter ASPEC1; 'Y': species incorporated in the model; 'N': species not incorporated in the model). The position of each character on this line indicates the species identification number. On the next line, coniferous and deciduous species are specified with the characters 'C' or 'D,' respectively (parameter ASPEC2). The position of each character is equal to the identification number. Browsing (parameter ABROW) can be turned on or off on line 5. On the same line the threshold temperatures for frost occurrence in March, April, and May (array AFROST) are specified. If the actual temperature in one of these

Table 4. Input data for program FORECE (part A, control parameters and scenario information)

```
KPRNT=005 KLAST=050 NYEAR=01200 PLOTS=Y SOILQ=000000045000.00 (KG PER 1/12HA)
START VALUES FOR RANDOM NUMBER GENERATOR: 73910 48206
YYYYYYYYNYYYYYYYYYYYYYYYYYYYYYY
CCCCCCCCCDDDDDDDDDDDDDDDDDDDDDD
BROWSING (Y OR N): Y  THRESHOLDS FOR FROST OCCURRENCE:  3.5   6.5   9.5
ADDITIONAL OPTIONS:  'OPTIMUM INFORMATION AFTER ELLENBERG (1978)'     N
(YES:Y OR NO:N)      'INDICATOR VALUES FOR TEMP. AND TEMPAMPL.'      Y
-----------------------------------------------------------------------------
SCENARIO 1: 'CLIMATIC CHANGE'   (MANDATORY)
SHOULD THE CLIMATIC SIMULATION BE THE SAME IN ALL PLOTS?             N
IPOLAT=02 (NUMBER OF BREAK POINTS IN LINEAR INTERPOLATION, MAX. 10)
     0.  1200.
MEANT1   -1.07  0.49  4.17  8.11 12.60 15.81 17.67 16.97 13.74  8.53  3.43  0.03
MEANT2   -1.07  0.49  4.17  8.11 12.60 15.81 17.67 16.97 13.74  8.53  3.43  0.03
STDDEV1   2.24  2.56  1.72  1.64  1.53  1.37  1.58  1.38  1.60  1.47  1.47  1.91
STDDEV2   2.24  2.56  1.72  1.64  1.53  1.37  1.58  1.38  1.60  1.47  1.47  1.91
MEANP1    5.78  5.47  6.50  7.80  9.77 11.74 11.43 11.45  8.94  7.21  7.46  6.51
MEANP2    5.78  5.47  6.50  7.80  9.77 11.74 11.43 11.45  8.94  7.21  7.46  6.51
STDDEV1   3.34  3.85  3.74  3.74  3.56  4.14  5.25  5.33  4.47  4.73  4.94  3.98
STDDEV2   3.34  3.85  3.74  3.74  3.56  4.14  5.25  5.33  4.47  4.73  4.94  3.98
-----------------------------------------------------------------------------
SCENARIO 2: 'AIR POLLUTION EFFECTS'                                  N
FLUORIDES:N STARTYR=   0 INT.=2 BREAK= 100 INT.=1 ENDYR=1200 INT.=2
SO2:      N STARTYR=   0 INT.=2 BREAK= 900 INT.=1 ENDYR=1100 INT.=1
NO2:      N STARTYR=   0 INT.=2 BREAK= 300 INT.=1 ENDYR= 900 INT.=2
NO3:      N STARTYR=  20 INT.=1 BREAK= 100 INT.=2 ENDYR= 250 INT.=2
-----------------------------------------------------------------------------
SCENARIO 3: 'SOIL CONDITION CHANGES'                                 Y
PH:       N STARTYR=   0 LEV.=3 BREAK= 100 LEV.=3 ENDYR= 250 LEV.=3
NITROGEN: N STARTYR=   0 LEV.=5 BREAK=  90 LEV.=6 ENDYR= 500 LEV.=7
WATERCONT:Y STARTYR=   0 LEV.=5 BREAK= 100 LEV.=5 ENDYR=1200 LEV.=5
-----------------------------------------------------------------------------
SCENARIO 4: 'HUMAN INTERVENTION'                                     N
FOREST TYPE ANTICIPATED        :  2  (1: UNEVEN AGED; 2: EVEN AGED)
IF UNEVEN-AGED STAND IS CHOSEN, PROVIDE ANTICIPATED DBH DISTRIBUTION:
 DBH-CLASS (CM):             0- 8  8-16 16-24 24-32 32-48 48-72   >72
 NUMBER OF TREES          :  300    20     8     4     4     3     2
IF EVEN-AGED STAND IS CHOSEN, PROVIDE ANTICIPATED STEM DENSITY FUNCTION
 MEAN DBH                      1     8    16    24    32    48   >72
 STEM DENSITY (TREES)       800.  300.  120.   60.   30.   15.    5.
BOTH FOREST-TYPES: PROVIDE PERCENTAGE OF FAVORED TREES IN EACH DBH-CLASS
 DBH-CLASS (CM)              0-8  8-16 16-24 24-32 32-48 48-72   >72
 %    FAVORED TREES          65.   80.   80.   80.   80.   80.   90.

INGROWTH METHOD:      2  (1: ONLY NATURAL; 2: NATURAL AND PLANTED)
PLANTED SPECIES AND QUANTITIES:
SPEC QUANT  SPEC QUANT  SPEC QUANT  SPEC QUANT  SPEC QUANT
  2   800    0     0     0     0     0     0     0     0
NUMBER OF SPECIES FAVORED:                               1
FAVORED SPECIES:                         2    0    0    0    0

ADDITIONAL INFORMATION:
UNEVEN-AGED STANDS: SCREENING THRESHOLD (YIELD OF FAVORITE TREES      5.
EVEN-AGED STANDS:   NUMBER OF MERCHANTABLE TREES BIGGER THAN DBH1     5
                    DBH1                                             50.
                    IDBH2                                             0
BOTH FOREST TYPES:  INITIAL SCREENING (YEARS)                         3
                    REMOVAL CYCLE FOR WOOD (YEARS)                   10
                    NUMBER OF YEARS WITHOUT ANY FOREST MANAGEMENT     3
                    DBH LIMITS FOR SCREENING                   0.   24.
                    DBH OF TREES CONSIDERED MERCHANTABLE (FAV. SP.)  50.
-----------------------------------------------------------------------------
PLAT=46.95 PLONG= 7.45 BGS=120. EGS=273. FC=30.0 DRY= 20.
NSPEC= 31
```

Table 5a. Input data for program FORECE (part B, individual species data). Missing values are indicated with -9999. Values marked with * were estimated by the taxonomic and ecological affinities of the corresponding species to the species with known values. For parameter explanation see Tables 3a and b.

Species	Parameter								
	INUM	DMAX	HMAX	AGEMX	B2[1]	B3[1]	G1	G2	DYG
ABIES ALBA	1	150	6000	800	7817	26	90	90	-9999
PICEA ABIES	2	120	5000	1000	8105	34	130	130	-9999
PINUS SYLVESTRIS	3	110	4800	600	8478	39	140	90	30
PINUS CEMBRA	4	200	2300	1200	2163	5	80	80	-9999
LARIX DECIDUA	5	150	5400	700	7017	23	130	130	-9999
PINUS STROBUS	6	200	6500	500	6363	16	130	130	-9999
PINUS MUGO	7	80	1000	500	2157	13	80	80	-9999
TAXUS BACCATA	8	50	1500	1500	5452	55	30	30	-9999
PSEUDOTSUGA MENZIESII	9	200	8000	1000	7863	20	140	140	-9999
FAGUS SYLVATICA	10	150	3500	350	4484	15	140	140	-9999
QUERCUS ROBUR	11	200	4000	1000	3663	10	140	110	30
QUERCUS PETREA	12	180	4000	700	4292	12	140	110	30
QUERCUS PUBESCENS	13	100	2000	600	3726	19	100	100	-9999
CARPINUS BETULUS	14	100	2000	250	3726	19	120	120	-9999
ACER PSEUDOPLATANUS	15	200	3000	600	2863	7	90	90	-9999
ACER PLATANOIDES	16	100	2500	400	4726	24	130	100	30
ACER CAMPESTRE	17	70	1500	200	3894	28	100	100	-9999
FRAXINUS EXCELSIOR	18	170	3500	250	3956	12	130	130	-9999
ULMUS SCABRA	19	60	3000	400	9543	80	110	110	-9999
TILIA CORDATA	20	300	2500	800	1575	3	80	80	-9999
TILIA PLATYPHYLLOS	21	300	3300	800	2109	4	80	80	-9999
BETULA VERRUCOSA	22	65	3000	120	8809	68	200	200	-9999
ALNUS INCANA	23	40	2000	100	9315	116	180	180	-9999
ALNUS GLUTINOSA	24	50	3000	300	11452	115	180	180	-9999
ALNUS VIRIDIS	25	40*	250	150*	565*	7*	180*	180*	-9999
POPULUS TREMULA	26	100	2000	150	3726	19	210	210	-9999
POPULUS NIGRA	27	200	2500	300	2363	6	200	200	-9999
SALIX ALBA	28	100	3000	150	5726	29	200	200	-9999
SORBUS ARIA	29	30	1200	200	7087	118	50	50	-9999
SORBUS AUCUPARIA	30	40	1700	120	7815	98	110	110	-9999
CASTANEA SATIVA	31	200	2500	800	2363	6	100	100	-9999

Species	Parameter								
	INUM	PRCOL	PRCOU	DEGMI	DEGMX	DEGOL	DEGOU	TEMOL	TEMOU
ABIES ALBA	1	11	24	420	4170	830	1500	4	7
PICEA ABIES	2	5	24	170	2060	280	940	0	7
PINUS SYLVESTRIS	3	4	10	390	2500	780	1670	4	12
PINUS CEMBRA	4	4	12	110	890	280	670	0	4
LARIX DECIDUA	5	4	12	110	2060	280	830	0	7
PINUS STROBUS	6	-9999	-9999	610	1760	-9999	-9999	-9999	-9999
PINUS MUGO	7	-9999	-9999	220	1670	-9999	-9999	-9999	-9999
TAXUS BACCATA	8	-9999	-9999	780	4170	-9999	-9999	-9999	-9999
PSEUDOTSUGA MENZIESII	9	-9999	-9999	330*	4060*	-9999	-9999	-9999	-9999
FAGUS SYLVATICA	10	10	24	500	4330	1390	1940	4	10
QUERCUS ROBUR	11	4	12	810	4330	1390	1940	8	12
QUERCUS PETREA	12	4	12	560	4330	1390	1940	8	12
QUERCUS PUBESCENS	13	13	24	780	4330	1940	2500	10	14
CARPINUS BETULUS	14	7	12	670	4330	1560	1940	7	11
ACER PSEUDOPLATANUS	15	-9999	-9999	670	4170	-9999	-9999	-9999	-9999
ACER PLATANOIDES	16	-9999	-9999	810	4440	-9999	-9999	-9999	-9999
ACER CAMPESTRE	17	-9999	-9999	830	4170	-9999	-9999	-9999	-9999
FRAXINUS EXCELSIOR	18	-9999	-9999	750	4170	-9999	-9999	-9999	-9999
ULMUS SCABRA	19	-9999	-9999	830	4890	-9999	-9999	-9999	-9999
TILIA CORDATA	20	-9999	-9999	1100	4170	-9999	-9999	-9999	-9999
TILIA PLATYPHYLLOS	21	-9999	-9999	1100	4170	-9999	-9999	-9999	-9999
BETULA VERRUCOSA	22	13	24	390	4330	1940	2500	10	14
ALNUS INCANA	23	-9999	-9999	390	3890	-9999	-9999	-9999	-9999
ALNUS GLUTINOSA	24	-9999	-9999	670	4890	-9999	-9999	-9999	-9999
ALNUS VIRIDIS	25	-9999	-9999	60	1000	-9999	-9999	-9999	-9999
POPULUS TREMULA	26	-9999	-9999	390	4330	-9999	-9999	-9999	-9999
POPULUS NIGRA	27	-9999	-9999	440	5060	-9999	-9999	-9999	-9999
SALIX ALBA	28	-9999	-9999	830	5060	-9999	-9999	-9999	-9999
SORBUS ARIA	29	-9999	-9999	670	5000	-9999	-9999	-9999	-9999
SORBUS AUCUPARIA	30	-9999	-9999	280	3890	-9999	-9999	-9999	-9999
CASTANEA SATIVA	31	13	24	1000	4450	1940	2500	10	14

[1] original value multiplied by 10^2 for program technical reasons; readjusted in the program

Table 5b. Input data for program FORECE (part B, individual species data). Missing values are indicated with -9999. Values marked with * were estimated by the taxonomic and ecological affinities of the corresponding species to the species with known values. For parameter explanation see Tables 3a and b.

Species	Parameter								
	INUM	ISPRT	IMAM	IF	ISO2	INO2	INO3	IDRT	ISHAW
ABIES ALBA	1	0	3	3	3	2	3*	3	1
PICEA ABIES	2	0	2	3	3	1*	2	1	3
PINUS SYLVESTRIS	3	0	2	3	3	2*	2	5	5
PINUS CEMBRA	4	0	3	2	2	2*	2*	5	3
LARIX DECIDUA	5	0	2	3	3	3	2	2	5
PINUS STROBUS	6	0	2*	2	2	2*	3	3*	3
PINUS MUGO	7	0	2	2	2	1	1*	5	5
TAXUS BACCATA	8	0	3	1	1	1	1*	4	1
PSEUDOTSUGA MENZIESII	9	0	1*	3	3	2*	2*	3*	4
FAGUS SYLVATICA	10	1	3	3	2	1	2	2	1
QUERCUS ROBUR	11	1	2*	0	1	1	1	5	5
QUERCUS PETREA	12	1	2	1	1	1*	1*	3	4
QUERCUS PUBESCENS	13	1	2*	1	1	1	1*	4	5
CARPINUS BETULUS	14	2	3	2	2	1	3	3	2
ACER PSEUDOPLATANUS	15	1	1*	2	1	2*	2	3	2
ACER PLATANOIDES	16	1*	1*	0	1	2	2*	3	2
ACER CAMPESTRE	17	1	1*	0	1	2*	1	4	3
FRAXINUS EXCELSIOR	18	1	2*	2	2	2*	2	2	2
ULMUS SCABRA	19	1	1*	0*	0*	1	1*	3	2
TILIA CORDATA	20	1	2*	3	2	2	3	3	3
TILIA PLATYPHYLLOS	21	1	2	3	2	2	2*	3	2
BETULA VERRUCOSA	22	1*	1*	2	0*	2*	2	2	5
ALNUS INCANA	23	2	2	1	1	3*	3	1	4
ALNUS GLUTINOSA	24	2	2	1	1	3*	3	1	3
ALNUS VIRIDIS	25	2	2	1	1	1*	1*	1*	1
POPULUS TREMULA	26	2	3	0*	1	1*	1*	3	4
POPULUS NIGRA	27	2	3*	0*	1	1*	1*	1	3
SALIX ALBA	28	2	1*	1	2	1*	1*	1	3
SORBUS ARIA	29	1	2*	2	2	1*	1*	4	4
SORBUS AUCUPARIA	30	1	2*	2	2	1*	1*	4	4
CASTANEA SATIVA	31	2	2*	1*	1*	1*	1*	4	3

Species	Parameter								
	INUM	IFRSS	AVJAN	ILIGH	ITENO	IAMPL	IMST1	IACID	INIT
ABIES ALBA	1	2	-5	4	5	4	6	5	5
PICEA ABIES	2	3	-7	5	3	6	5	-9999	5
PINUS SYLVESTRIS	3	5	-9999	7	5	7	3	-9999	3
PINUS CEMBRA	4	5	-10	5	2	7	5	5	4
LARIX DECIDUA	5	3	-10	8	2	6	4	3	3
PINUS STROBUS	6	3*	-9999	5	7	5	5	-9999	3
PINUS MUGO	7	5	-9999	8	4	6	5	5	3
TAXUS BACCATA	8	4	-9999	4	6	2	5	7	3
PSEUDOTSUGA MENZIESII	9	4*	-9999	4	5	3	5	5	5
FAGUS SYLVATICA	10	1	-4	4	5	2	5	-9999	5
QUERCUS ROBUR	11	3	-3	7	6	5	6	-9999	5
QUERCUS PETREA	12	3	-3	6	6	2	3	-9999	3
QUERCUS PUBESCENS	13	2	-9999	7	8	4	3	7	-9999
CARPINUS BETULUS	14	3	-9999	4	6	4	5	5	5
ACER PSEUDOPLATANUS	15	3	-9999	4	5	4	6	5	5
ACER PLATANOIDES	16	3	-9999	4	6	4	5	7	5
ACER CAMPESTRE	17	3	-9999	5	6	4	5	7	6
FRAXINUS EXCELSIOR	18	1	-9999	4	5	3	7	7	7
ULMUS SCABRA	19	4	-9999	4	5	3	7	5	7
TILIA CORDATA	20	3	-9999	5	5	4	4	5	5
TILIA PLATYPHYLLOS	21	3	-9999	4	5	2	5	-9999	7
BETULA VERRUCOSA	22	5	-9999	7	5	5	7	-9999	3
ALNUS INCANA	23	4	-9999	6	4	5	7	8	7
ALNUS GLUTINOSA	24	3	-9999	5	5	3	9	6	7
ALNUS VIRIDIS	25	4*	-9999	7	3	4	6	5	7
POPULUS TREMULA	26	5	-9999	6	5	5	5	5	5
POPULUS NIGRA	27	4	-9999	5	7	6	8	7	7
SALIX ALBA	28	4	-9999	5	6	6	8	8	7
SORBUS ARIA	29	3	-9999	6	5	3	3	7	3
SORBUS AUCUPARIA	30	5	-9999	6	4	5	3	-9999	-9999
CASTANEA SATIVA	31	1	-9999	5	8	2	4	4	-9999

Table 5c. Input data for program FORECE (part B, individual species data). Missing values are indicated with -9999. Values marked with * were estimated by the taxonomic and ecological affinities of the corresponding species to the species with known values. For parameter explanation see Tables 3a and b.

Species	Parameter							
	INUM	ISEXM	IMST2	A1[2]	A2[2]	C1[3]	C2[4]	DRANG[2]
ABIES ALBA	1	65	6	-2511	1959	45	70*	1628
PICEA ABIES	2	55	5	-2582	1904	47	67	1335
PINUS SYLVESTRIS	3	35	3	-2256	1577	45	52	519
PINUS CEMBRA	4	75	5	-2580*	1904*	45*	70*	1270*
LARIX DECIDUA	5	35	4	-3179	1639	40	81	249
PINUS STROBUS	6	35	5	-2580*	1904*	45*	70*	1270*
PINUS MUGO	7	8	3	-2250*	1580*	45*	70*	499*
TAXUS BACCATA	8	25	5	-2511*	1960*	45*	70*	1693*
PSEUDOTSUGA MENZIESII	9	35	5	-2846	1701	100	174	1000
FAGUS SYLVATICA	10	70	4	-3093	1792	38	155	455
QUERCUS ROBUR	11	75	8	-3113	1784	35	132	404
QUERCUS PETREA	12	70*	3	-3113	1784	35	132	404
QUERCUS PUBESCENS	13	60*	3	-3113*	1784*	35*	132*	404*
CARPINUS BETULUS	14	35	5	-3090*	1800*	35*	140*	395*
ACER PSEUDOPLATANUS	15	45	6	-3000*	1750*	35*	140*	356*
ACER PLATANOIDES	16	35	5	-3000*	1750*	35*	140*	356*
ACER CAMPESTRE	17	40*	5	-3000*	1750*	35*	140*	356*
FRAXINUS EXCELSIOR	18	45	6	-2800*	1700*	35*	140*	358*
ULMUS SCABRA	19	40*	6	-3000*	1750*	35*	140*	356*
TILIA CORDATA	20	35	4	-3000*	1750*	35*	140*	356*
TILIA PLATYPHYLLOS	21	35	5	-3000*	1750*	35*	140*	356*
BETULA VERRUCOSA	22	25	8	-2950*	1580*	35*	140*	203*
ALNUS INCANA	23	15	7	-3100*	1750*	35*	140*	322*
ALNUS GLUTINOSA	24	40	9	-3100*	1750*	35*	140*	322*
ALNUS VIRIDIS	25	15*	6	-3100*	1750*	35*	140*	322*
POPULUS TREMULA	26	25	5	-3100*	1700*	35*	140*	265*
POPULUS NIGRA	27	25*	8	-3100*	1700*	35*	140*	265*
SALIX ALBA	28	20*	8	-3100*	1700*	35*	140*	265*
SORBUS ARIA	29	20*	3	-3100*	1700*	35*	140*	265*
SORBUS AUCUPARIA	30	20	3	-3100*	1700*	35*	140*	265*
CASTANEA SATIVA	31	50	6	-3100*	1800*	40*	150*	450*

[2,3,4] original value multiplied by 10^3, 10^2, or 10^1, respectively for program technical reasons; readjusted in the program

months is one standard deviation below the average temperature and threshold temperature, frost may occur (for details see subroutine BIRTH). Lines 6 and 7 of the first block are switches for additional options ('Y': option turned on; 'N': option turned off). If the option "optimum information after Ellenberg (1978)" is chosen, the forest simulator favors species whose growth is optimum within a certain temperature and precipitation range (Ellenberg 1978). The option "indicator values for temperature and temperature amplitude" implies that the species-specific indicator values for temperature and temperature amplitude (Ellenberg 1978; Landolt 1977) are checked to determine if a species is eligible to grow under certain climatic conditions.

The second input block contains climatic information on the forest ecosystem to be simulated. In most cases the data can be derived from an official meteorological station that represents the environmental conditions of the stands. Initially (line 10, parameter AFIX), the user may decide if the stochastic climatic simulation should be the same for each replicate or if it should be altered ('Y': same climatic simulation on all plots; 'N': climatic simulation changes). 'IPOLAT' (line 11) is the number of break points in the climatic simulation, indicating how often the mean climatic conditions are altered during the whole succession. The corresponding years of climatic change are read into array 'X' (line 12). The changes are gradual, and a linear interpolation is made between 2 years with different climate. On the next lines (positions 13-20, depending on the number of break points requested), the mean climatic conditions of each break point are determined and read into arrays 'TSAV' (mean temperature data, °C), 'VTSAV' (standard deviation of the temperature values, °C), 'RSAV' (mean precipitation data, cm), and 'VRSAV' (standard deviation of the precipitation values, cm). If the climatic scenario is to be held constant, two identical lines should be read into the corresponding arrays. If the climatic conditions change, each line should contain different data.

Influences of air pollutants such as fluorides, $\underline{SO_2}$, and $\underline{NO_x}$ may be simulated by turning on the switch on line 22 ('Y': on; 'N': off). The presence of each air pollutant can be simulated independently by turning on the corresponding switches on lines 23 through 26 (array AIRP). The concentration levels (INT) are expressed on a nominal scale between 0 and 2 (0: very low; 1: intermediate; 2: high) and can be varied over time. Three break points (STARTYR; BREAK; ENDYR) indicate intervening years, between which the air pollution concentration is interpolated linearly.

Lines 28 through 31 contain information about the soil conditions on the sites to be simulated. The scenario is optional and may be turned on ('Y') or off ('N'). Three edaphic factors such as acidity (PH), nitrogen content (NITROGEN), and water content (WATERCONT) may be incorporated into the model. Each is optional and may be turned on or off individually ('Y': parameter will be used; 'N': parameter will not be used). The soil conditions can be varied through time with three break points (STARTYR; BREAK; ENDYR) indicating intervening years, between which the nominal numbers for the soil characteristics (LEV) are interpolated linearly. The qualitative scale is similar to that introduced by Ellenberg (1978). A value of 1 for each parameter means that the soil is very acid, very low in nitrogen, and very dry. A value of 9 for each parameter indicates that the soil is alkaline, high in nitrogen, and moist.

Human intervention and forest management are controlled with the parameters in block 5 (lines 33-61). The scenario switch is on line 33 ('Y': scenario turned on; 'N': scenario turned off). All values are based on a plot size of 1/12 ha. Diameter values are given in centimeters. Two main forest types can be anticipated, namely, even-aged and uneven-aged stands (line 34, parameter IFTYP). Depending on the forest type chosen, the user has to provide several stand characteristics. If uneven-aged conditions are desired, a theoretical dbh distribution must be specified in array 'IDIST' (line 37). Line 40 contains information about the desired stem density on even-aged stands (array STEMDY). For both forest types, the anticipated percentage of trees of the favored species in each dbh class (array ARATIO) has to be provided on line 43. On the lines 45 through 48, the method of tree establishment (ingrowth) is indicated, including information about the species that may be planted (species identification and quantities of planted seedlings). Favoritism toward tree species is controlled on lines 49 and 50. The total number of favored species is expressed on line 49 (max 5), whereas the identification numbers of the favored species are given on line 50.

Lines 57 through 61 have to be considered for both forest types. To avoid favoritism toward species that are not present on a plot, the forest composition is occasionally screened. The year of the first screening is indicated on line 57 (parameter ISCREN). The user may specify the dbh classes of the trees used for the screening on line 60 (parameters ALIM1, ALIM2). On the lines 58 and 59, the frequency of wood removal (parameter ICYC1) and the number of years without forest management (parameter IFIRST) are determined. The user may also specify the dbh of trees considered as merchantable (parameter ALIM3, line 61). This parameter is used to determine whether a forest's yield is sufficient.

If an uneven-aged stand is anticipated, the forest simulator checks each year of the succession to determine whether enough trees of merchantable size (see line 61) have been harvested. To this end the ratio (R) is calculated and compared with the value 'ALIM4', given on line 53,

$$R = (NHV/NSC) * 100 \quad , \qquad (1)$$

where

NHV = number of harvested trees (favored species, valuable size);
NSC = number of trees (favored species) at the time of screening.

If (R) is greater than or equal to 'ALIM4', a new screening occurs.

For even-aged stands, lines 54 through 56 must be specified to regulate clear cuts. The value given on line 54 (parameter IHARV) indicates the number of trees above a certain minimum size (parameter DBH1, line 55) that must be present on the plot to trigger a clearcut. If a clearcut occurs, all trees greater than the dbh class given on line 56 are cut [key to the dbh classes: 0.0-7.9 cm (class 1); 8.0-15.9 cm (class 2); 16.0-23.9 cm (class 3); 24.0-31.9 cm (class 4); 32.0-47.9 cm (class 5); 48.0-71.9 cm (class 6); and greater than 72 cm (class 7)]. If the number on line 56 is 0, all trees are cut.

The last lines of the run-control parameters (lines 63 and 64) are similar to the parameters described by Pastor and Post (1985) and are explained in Tables 3a and b. Field moisture capacity (parameter FC) and wilting point (DRY) are expressed in centimeters of water in soil to a certain depth.

The second part of the data input contains information on individual species (Tables 5a-c) that was compiled from silvics literature and phytosociological descriptions. Table 6 gives an overall picture of the literature used to derive the parameters. The information required to run a JABOWA-type model was not always readily available for European tree species. Thus the conventional data base was modified to fit the available information. However, the basic data parameters such as maximum diameter (DMAX); maximum height (HMAX); maximum age of a species (AGEMX); degree day range (DEGMI, DEGMX); sprouting tendency (ISPRT); and shade tolerance (ISHAW) have not been changed. The calculation for growing degree days follows procedures described by Hare and Thomas (1979), and Mielke (1978). Degree days are defined as the sum of the positive Celsius degree differences in temperature between the actual mean temperature for each day and 5.55°C. To calculate degree days from average monthly minimum and maximum temperature for a certain climatic station the data were fitted with a sine function. The degree day range of different species was obtained by using species distribution maps (Meusel 1965, 1978) and degree day maps compiled for Europe, Central Asia, and the Mediterranean (Great Britain Meteorological Office 1982; Rudloff 1981). The vertical distribution of the tree species in the Alps was also considered a derivation for degree day limits. To this end,

Table 6. Literature references for the individual species data used in FORECE

Parameter	References	Parameter	References
AGEMX	1,2,3,7	IF	2,12
AVJAN	2,5	IFRSS	2,5
A1,A2	3,8	ILIGH	5
B2,B3	1,2,3,7,11	IMAM	1,4,5
C1,C2	3,8	IMST1,IMST2	5
DEGMI,DEGMX	6,9,10	INIT	5
DEGOL,DEGOU	5,9,10	INO2	2,12
DMAX	1,2,3,7	INO3	2,12
DRANG	3,8	ISEXM	1
DYG	8,14	ISHAW	1,2,3,5,11,13
G1,G2	8,11,14	ISO2	2,12
HMAX	1,2,3,7	ISPRT	1
IACID	5	ITENO	5
IAMPL	5	PRCOL,PRCOU	5
IDRT	2	TEMOL,TEMOU	5

1: Amann (1954)
2: Bernatzky (1978)
3: Dale and Hemstrom (1984)
4: Dengler (1972)
5: Ellenberg (1978)
6: Ellenberg and Klötzli (1972)
7: Hess et al. (1967, 1970, 1973)
8: Mitscherlich (1970)
9: Meusel (1965, 1978)
10: Rudloff (1981)
11: Shugart and West (1977)
12: Smith (1981)
13: Stern and Roche (1974)
14: SFIFR (1967, 1969, 1983a,b)

degree days were calculated for different altitudinal levels using climatic stations of the Swiss Meteorological Service (1901-1986) and data from Walter and Lieth (1960, 1964, 1967).

Compared with previous succession models for the eastern part of North America, several input parameters were modified (i.e., IDRT, AVJAN) or omitted (i.e., minimum and maximum diameter for sprouting and recruiting switches; Shugart and West 1977) since an equivalent data base was not available for Central European species. An important modification is the incorporation of the indicator value concept described by Ellenberg (1978) and Landolt (1977). The following indicator values are used (partially optional): soil moisture (IMST1, IMST2); reaction value or acidity index (IACID); nitrogen value (INIT); light intensity value (ILIGH); and temperature and continentality index (ITENO, IAMPL). These are nonmeasurable values based largely on distribution maps and observations of the botanist in the field. The values are well suited to the precision level of the model and represent an important information source. However, the indices do not simply express the physiological possibilities of the plant, and interspecies competition may alter the values remarkably. These interpretation limits have to be considered for all model runs using the indicator values.

The remaining parameters 'PRCOL', 'PRCOU', 'DEGOL', 'DEGOU', 'TEMOL', and 'TEMOU' indicate climatic conditions that favor growth of certain species and may lead to their dominance. Also, each species' sensitivity to major air pollutants (NO_x, SO_2, and HF) is given (parameters INO2, INO3, ISO2, and IF).

3.3 SUBROUTINE PLOTIN

PLOTIN initializes variables to start a succession on a bare plot or with a given forest composition. To specify an existing species distribution at the beginning of the succession, the arrays 'NTREES', 'DBH', and 'IAGE' must contain the desired number of trees, their dbh, and corresponding age.

3.4 SUBROUTINE TEMPE

Subroutine TEMPE calculates growing season degree days (DEGD) based on the monthly temperatures for the current year of the simulation (Pastor and Post 1985). First, LINIT is called to make linear interpolations of the long-term monthly temperatures and standard deviations between different break points (years) of climate. The interpolated data are provided in the arrays 'T' and 'VT', respectively. Subsequently, TEMPE calculates a random temperature value that is normally distributed around the mean value of each month:

$$RT(I) = T(I) + VT(I) * \text{RANDOM NUMBER} \qquad (I = 1,12) \qquad (2)$$

The normally distributed random number is provided by an IBM system routine and has a value between 0 and 1. If the user desires the climatic simulation to be identical in all replicates, the random number of the first plot will be stored in array 'RANUT'. The number of degree days (DEGD) for a specific year is calculated by Eq. (3).

$$DEGD = \sum_{I=1}^{12} [RT(I) - DDBASE] * DAYS(I) \quad , \qquad (3)$$

where 'DDBASE' is a base temperature (in this case 5.55 °C) above which degree days are counted. DAYS(I) are the number of days in any given month. Degree days are counted only if the average temperature of a month is above 'DDBASE'.

3.5 SUBROUTINE MOIST

Subroutine MOIST follows exactly the code of Pastor and Post (1985). Thus, only the main features are described. MOIST calculates the number of days of the growing season having inadequate soil moisture (parameter FJ) by using a simple soil water/evapotranspiration approach. The amount of water a soil can hold is expressed by the field capacity (FC; cm) and the wilting point (DRY; cm). Available soil water for plants is the difference between the soil water content at field capacity and the amount of water at the wilting point. The wilting point is assumed to have a soil water tension of -15×10^{15} Pa.

Potential evapotranspiration 'U' is calculated using the formula of Thornthwaite and Mather (1957), which seems to be appropriate for the precision of the model. Monthly potential evapotranspiration is calculated as

$$U = 1.6 * \{[10.0 * RT(I)/TE]^{**}A\} * CLAT(I,LAT) \quad (I = 1,12), \qquad (4)$$

where

RT(I) is the mean temperature for month I;

CLAT (I,LAT) adjusts the monthly evapotranspiration values to account for latitude, day length, and number of days in a month;

LAT is the latitude pointer for the station;

TE is the temperature efficiency index according to Eq. (5);

$$TE = \sum_{K=1}^{12} \{[0.2 * RT(K)]^{**}1.514\}; \qquad (5)$$

A is a function of TE according to the empirically derived formula displayed in Eq. (6) (Pastor and Post 1985);

$$A = 0.000000675 * (TE)^{**}3 - 0.0000771 * (TE)^{**}2 + 0.01792 * TE + 0.49239. \qquad (6)$$

It is assumed that the soil is always saturated in spring and that the soil field capacity is always reached. Monthly precipitation in any given year is randomly calculated around the interpolated monthly mean of the climatic station given in the INPUT file. As long as precipitation satisfies water loss by evapotranspiration, the soil moisture content is the maximum water a soil can hold at field capacity. If precipitation is not sufficient, the potential water loss (PWL) is calculated as the difference between potential evapotranspiration (U) and the month's precipitation. The amount of water retained in the soil is then calculated after the formula of Pastor and Post (1985)

$$WATER = FC * \exp[(0.000461 - 1.10559/FC)*(-ACCPWL)] \quad , \qquad (7)$$

where 'ACCPWL' is the sum of potential water loss (PWL). Finally, the number of dry days is determined following an algorithm described in Pastor and Post (1985).

3.6 SUBROUTINE GMULT

GMULT calculates growth multipliers used in the subroutines BIRTH and GROW. Growth multipliers indicate to what extent soil moisture, degree days, and other environmental factors are less than optimum for the growth of different species. They normally range on a scale from 0 (conditions that inhibit growth) to 1 (conditions optimum for growth). The degree day growth multiplier for each species [DEGDGF(I)] represents an attempt to simulate the effects of temperature on the photosynthetic rate. It is assumed that each species has an optimum temperature for photosynthesis and that the photosynthetic rate decreases along a parabola with increasing positive or negative difference of the actual temperature from the optimum temperature (Botkin et al. 1972). The symmetrical parabolic function has its x-intercepts at 'DEGMI' (minimum degree days for species) and 'DEGMX' (maximum degree days for species) and the maximum of 1.0 at [(DEGMX-DEGMI)/2] (Fig. 1b). If the option 'optimum information after Ellenberg (1978)' is turned on and the degree-day conditions of the current year are within the limits for optimum growth and dominance of a certain species (DEGOL; DEGOU), the growth multiplier is set equal to 1.0.

The soil moisture growth multiplier 'SMGF' is calculated according to Pastor and Post (1985). The driving variable is the number of growing season days in which soil moisture is below the wilting point (Figure 1c). The multiplier (SMGF) is derived from Eq. (8a) or (8b).

$$SMGF = \begin{cases} SQRT\{[D3(I)*TGS - FJ]/[D3(I)*TGS]\} & FJ < D3*TGS \quad (8a) \\ 0 & FJ > D3*TGS \quad (8b) \end{cases}$$

$$(I = 1, NSPEC)$$

The equation follows a study of Basset (1964) who showed that basal area increment is linearly related to the number of drought days during the growing season for southern U.S. pines. 'FJ' is the number of dry days, 'TGS' is the total number of growing days, and 'D3(I)' is the maximum proportion of dry days from the total growing days each species can withstand. Usually, the factor 'D3(I)' is derived from soil moisture maps (e.g., Pastor and Post 1985). However, because of the complicated precipitation and species distribution pattern in Europe, this procedure turned out to be incongruous. Thus, the factor 'D3(I)' was derived from phytosociological descriptions of drought resistance (parameter IDRT) (Amann 1954; Ellenberg 1978). The species were ranked on a nominal scale from 1 to 5, where the proportion of dry days tolerated was assigned to each drought resistance class (0.1 to class 1, 0.2 to class 2, 0.3 to class 3, 0.4 to class 4, and 0.5 to class 5).

Additional growth multipliers may be added to the model by turning on scenario 3. By doing so the individual species values for soil acidity (IACID), soil nitrogen content (INIT), and soil moisture (IMST1, IMST2) (Ellenberg 1978; Landolt 1977) of each species are compared with the actual conditions on the stand, as specified by the user (see subroutine INPUT). Actual conditions are expressed on the same descriptive scale as the individual species values (1 to 9). They might be varied over time (as described in subroutine INPUT), with a linear interpolation between two break points being performed. The deviation between the actual value of each soil parameter and the corresponding indicator value of each species determines the proportion of optimum growth. A normal distribution function was arbitrarily chosen to express the decreasing proportion of optimum growth with increasing differences between actual soil conditions and the individual species values. Figure 3 may facilitate an understanding of the procedure with an example of the optional soil moisture growth multiplier. The additional growth multipliers, based on the indicator value concept, are descriptive and static traits. They do not vary dynamically from year to year as do other growth multipliers, and should only be used to describe the general soil conditions. The optional descriptive soil moisture growth factor may be turned on together with the dynamic soil moisture growth multiplier that is calculated routinely (SMGF). Because the diameter increment equation is not a multiplicative function of all growth-reducing factors, an overestimation of soil moisture effects is unlikely.

3.7 SUBROUTINE BIRTH

Subroutine BIRTH simulates recruiting of new seedlings or new sprouts and manages human planting. A random number procedure determines the number of cycles through the main planting loop (DO-140; maximum three loops). First, the environmental conditions for ingrowth are assessed for each year of the simulation. They include the calculation of available light at the forest floor, long-term temperature mean of the meteorological station indicated in the INPUT file, and browsing influences.

3.7.1 Available Light at the Forest Floor (AL)

This parameter is calculated as a function of the leaf area index (XLAI) using a formula suggested by Mielke et al. (1978) and Shugart (1984).

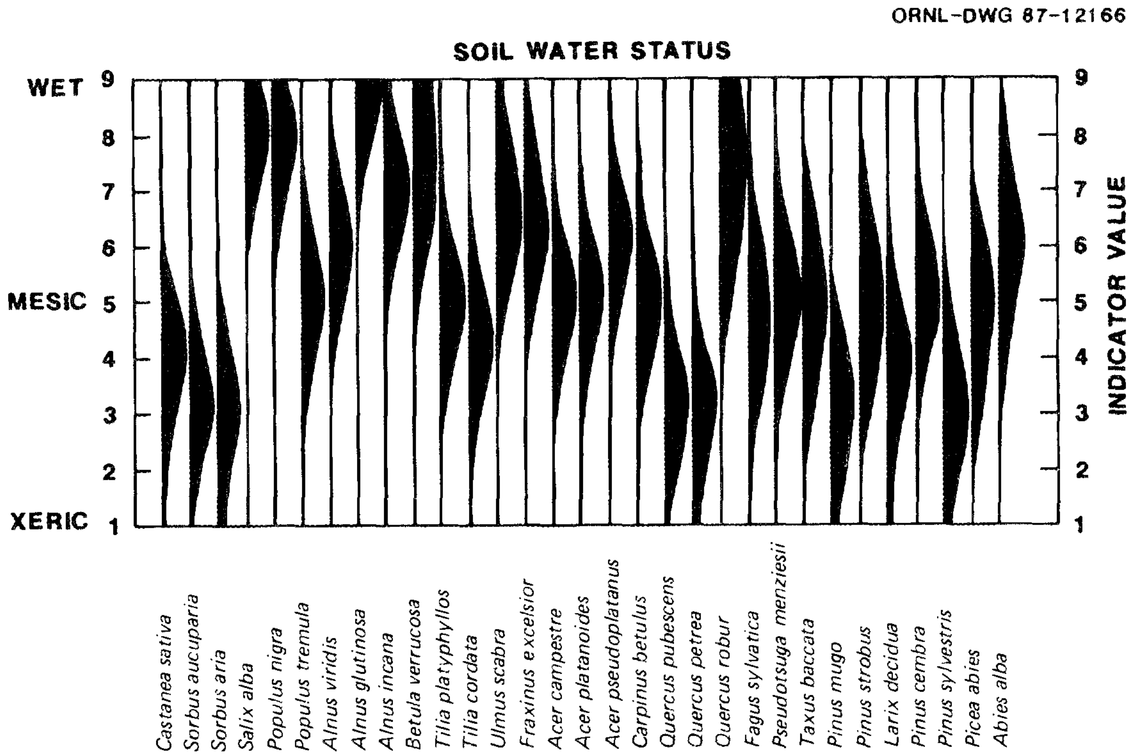

Fig. 3. The indicator value concept of Ellenberg (1978), as incorporated into the FORECE model. The graph shows under which soil moisture conditions the 31 species are most likely to be present. An arbitrarily chosen normal distribution function indicates the decreasing proportion of optimum growth with increasing differences between actual value and individual species value. If actual value and individual species value (IMST1 or IMST2) are identical, a growth multiplier of 1.0 is assigned. Values for species not included in Ellenberg's system or with an indifferent behavior were estimated by their taxonomic and ecological affinities to the species with known values. The equivalent system of Landolt (1977) was also consulted.

$$AL = PHI * EXP(-0.25 * XLAI) \quad , \qquad (9)$$

where 'PHI' is the annual insolation in appropriate units (in the current model a default value of 1 is used). Leaf area index (XLAI) is expressed as the sum of leaf area (LA) of each tree divided by the plot size [Eq. (10)]. Leaf area (LA) is a function of foliage biomass which was calculated according to Eqs. (11a) and (11b).

$$XLAI = \{\sum_{I=1}^{NSPEC} \sum_{K=1}^{NTREES(I)} [C2(I) * FBIW(K)]\}/833.33 \quad , \qquad (10)$$

where:

FBIW(K) = foliage biomass for each tree (kg, fresh weight);

C2(I) individual species parameter that converts foliage biomass (kg, fresh weight) into leaf area (m^2);

833.33 is the plot size in m^2 (1/12 ha).

Foliage biomass [FBIW(K)] is calculated according to a formula suggested by Dale and Hemstrom (1984) [Eqs. (11a) and (11b)].

$$FBIW(K) = \begin{cases} EXP\{A1(I) + [A2(I) * ALOG(DBH(K))]\} & dbh < 50 \text{ cm} \quad (11a) \\ \{[256.* ALOG(DBH(K)) - 639.] * 2.5 * DRANG(I)\}/[17.4 * C1(I)] & dbh > 50 \text{ cm} \quad (11b) \end{cases}$$

$$\{I=1,NSPEC;\ K=1,NTOT[NTREES(I)]\} \quad ,$$

where

A1(I) and A2(I) are individual species parameters,

C1(I) converts fresh needle weight to dry weight (kg),

DBH(K) is the diameter at breast height for each tree (cm),

DRANG(I) is the ratio of the foliage biomass of each species to that of *Pseudotsuga menziesii* at a dbh of 50 cm

(Note: Index K ranges from 1 to NTOT (total number of trees) in blocks of NTREES(I), which is the number of trees for each species.

As long as the diameter of a tree is below 50 cm, an exponential relationship between foliage biomass and diameter is assumed. A natural logarithm function is chosen for trees larger than 50 cm. Because no data were available for trees larger than 50 cm dbh, foliage biomass is estimated indirectly by using data for Pseudotsuga menziesii that were obtained by regression analysis (Dale and Hemstrom 1984). To this end, foliage biomass of each species at dbh = 50 cm was divided by foliage biomass of Douglas fir at dbh = 50 cm to obtain the multiplier 'DRANG(I)'.

The individual species constants in the suggested formulas were estimated using the available data of Burger cited in Mitscherlich (1970) (Table 7). Parameter 'C2' was derived by fitting a linear regression model to the foliage biomass data vs leaf area data at the corresponding dbh values. The regression curve was forced to originate at point 0/0. 'A1' and 'A2' were calculated by fitting a linear regression model to the logarithmic values of the foliage biomass data vs dbh data. The logarithmic approach was used to transform the exponential formula into a linear form. 'C1' was derived from tables in Mitscherlich (1970).

3.7.2 Frost, Browsing

Frost may occur if the current temperature of any of the months of March, April, or May is below the long-term mean minus one standard deviation and below the corresponding threshold values 'AFROST'. A random number procedure ascertains the severity of frost on a nominal scale between 0 and 5. Depending on the magnitude of the frost event and the frost tolerance of each species (parameter IFRSS), recruitment may be inhibited. Finally browsing influences are simulated. Browsing occurs randomly - a random number procedure determining if browsing affects only the highly sensitive or also the moderately sensitive species (parameter IMAM).

Table 7. Foliage biomass and leaf area data at different dbh for important central European species, including individual species constants derived from the data (after Burger citation in Mitscherlich 1970)

Species	Foliage biomass (fresh weight, kg)					Leaf area (m^2)					Species-specific constants				
	DBH (cm)					DBH (cm)									
	10	20	30	40	50	10	20	30	40	50	A1	A2	C1	C2	DRANG
Fagus sylvatica	3	9	19	34	54	60	158	300	520	840	-3.093	1.792	0.38	15.5	0.455
Quercus robur	3	8	18	33	52	38	100	235	440	-	-3.113	1.784	0.35	13.2	0.404
Larix decidua	2	5	10	18	28	25	53	90	140	-	-3.179	1.639	0.40	8.1	0.249
Pinus sylvestris	4	12	21	3	52	25	63	120	190	275	-2.256	1.577	0.45	5.2	0.519
Picea abies															
even-aged	6	22	32	52	81	-	-	-	-	-	-1.738	1.557	0.47	-	0.845
uneven-aged	6	23	50	85	128	50	180	354	580	810	-2.582	1.904	0.47	6.7	1.335
Abies alba															
even-aged	7	24	53	88	129	-	-	-	-	-	-2.259	1.823	0.45	-	1.288
uneven-aged	7	31	66	112	163	-	-	-	-	-	-2.511	1.959	0.45	-	1.628

3.7.3 Establishment of new seedlings

As soon as the environmental conditions considered are available for the current year, the program prepares a list of eligible species for planting, if they pass the following tests (DO-60 loop):

Default version:

1. Long-term average January temperature above the tolerated value (parameter AVJAN);
2. Available light at the forest floor sufficient for seedling (parameter ILIGH);
3. Degree days within the degree day tolerance limits of the species (parameters DEGMI, DEGMX);
4. Frost or browsing does not inhibit seedling (parameter IFRSS or IMAM respectively).

Optional version:

1. Long-term annual mean temperature above lowest value tolerated by the species (parameter ITENO),
2. Long-term temperature amplitude smaller than lowest value tolerated by the species (parameter IAMPL).

According to the list of eligible species, new seedlings are introduced. If only natural tree establishment occurs, the number of new individuals is determined by a random number procedure. Between 0 and 10 seedlings are planted in each birth cycle. The number of plants depends on the seed availability of a species. It is assumed that a basic amount of seeds are equally available for each species. This amount increases, the more trees of a certain species are older than 'ISEXM' years and therefore are able to produce seed. If planting occurs under a forest management plan designed for uneven-aged stands, the number of new trees is calculated automatically (for details see subroutine HUMINT). If planting occurs under a forest management plan that anticipates even-aged forests, the number of new seedlings is determined by the user and is constant throughout the whole simulation (array IPLANT). Each seedling is assigned a randomly distributed dbh between 1.27 and 1.42 cm.

As an additional option, the chances of a species being chosen from the seed pool can be increased. The option is turned on or off on line 6 of the input file ("optimum information after Ellenberg (1978)"). Consequently, the program determines (for each species), if the long-term temperature and precipitation conditions on the simulated plots are within the critical limits for species dominance (parameters TEMOL, TEMOU, PRCOL, PRCOU) (Ellenberg 1978). At the end of subroutine BIRTH, the arrays 'IAGE', 'DBH', and 'NOGRO' are rearranged and subroutine SPROUT is called. The initial birth process (at the beginning of the simulation or after a complete tree removal) continues until the leaf area index (XLAI) is bigger than 1 m^2/m^2.

3.8 SUBROUTINE SPROUT

This subroutine determines if any trees of a species are capable of sprouting. Consequently, the individual species parameter 'ISPRT' must be 1 or 2, and a dead stump of a certain minimum diameter must be available. The latter information is supplied by subroutine KILL in array 'KSPRT'. Eligible species are selected randomly. Also, the number of sprouts per sprouting tree is determined using a random number procedure. Up to 2 stems per stump are possible for species with a sprouting tendency of 1, whereas species with a sprouting tendency of 2 might have up to 3 sprouts per stump. The dbh of the new individuals is randomly distributed around 0.1 cm. For each run through subroutine SPROUT, one tree might sprout.

3.9 SUBROUTINE GROW

Subroutine GROW calculates the growth of any tree on the plot by reducing the maximum physiological diameter increment to the extent that the environmental factors are less than optimum. All growth multipliers except the light factor affect trees independently of their size or sociological position. The light multiplier, however, is determined for each given tree (j) by attenuating the incident radiation by the sum of leaf areas for all trees taller than tree (j). Consequently, the vertical distribution of foliage biomass in the canopy is calculated in units of 10 cm. The height of each tree [H(K)] is determined using the basic growth equation given by Ker and Smith (1955).

$$H(K) = 137 + B2(I)*DBH(K) - B3(I)*[DBH(K)**2] \quad (12)$$

$$\{ I = 1,NSPEC; K = 1,NTOT[NTREES(I)]\} \quad ,$$

where 'B2(I)' and 'B3(I)' are individual species parameters quantifying the tree form. The number 137 is the height of the tree in centimeters at dbh = 0.0cm. Assuming that a tree has its maximum height (HMAX) when reaching its maximum diameter (DMAX), the derivative dH/dDBH is equal to 0, and the formula can be solved after B2(I) and B3(I) (Shugart 1984)

$$B2(I) = 2*[HMAX(I) - 137]/DMAX(I) \qquad (I = 1,NSPEC) \qquad (13)$$

$$B3(I) = [HMAX(I) - 137]/[DMAX(I)]**2 \qquad (I = 1,NSPEC) \qquad (14)$$

To calculate the height profile, the formula is rearranged and the constant (137) is eliminated, since only the relative height distribution is of interest. The formula for the height of a tree in intervals of 10 cm [IHT(K)] takes the form

$$IHT(K) = [B2(I)*DBH(K) - B3(I)*DBH(K)**2]/10. + 1.0 \qquad (15)$$

$$\{I = 1,NSPEC; K = 1,NTOT[NTREES(I)]\} \; .$$

The foliage biomass of all trees of approximately the same height (same 10-cm interval) is then calculated using the formulas described in subroutine BIRTH [Eqs. (11a) and (11b)]. Subsequently, leaf area is determined [Eq. (10)], and a vertical profile of leaf area indices is calculated throughout the canopy (parameter SUMLA). Also, dry stemwood biomass [SBID(K)] is calculated for each tree and then accumulated over the whole plot. The formula follows an algorithm suggested by Sollins et al. (1973)

$$SBID(K) = 0.1193 * DBH(K)**2.393 \qquad (K = 1,NTOT) \qquad (16)$$

Dry stemwood biomass and dry foliage biomass of the plot are used to calculate the competition factor 'DCOMP' suggested by Botkin et al. (1972). This is a hypothesized proxy for nutrient competition of the form

$$DCOMP = 1.0 - \left\{ [\sum_{K=1}^{NTOT} SBID(K)] + [\sum_{K=1}^{NTOT} FBID(K)] \right\} /SOILQ \quad , \qquad (17)$$

where 'FBID(K)' is the dry foliage biomass of a tree obtained by dividing the wet foliage biomass [FBIW(K)] by the individual species constant C1. 'SOILQ' is the maximum recorded biomass on a plot of 1/12 ha in the ecosystem simulated.

The DO-80 loop is the main loop for calculating the diameter increment of each tree. Without the influence of any growth-limiting factors, a tree's maximum potential growth can be estimated by determining how close it is to its maximum volume and how fast it reaches this stage. The optimum diameter increment [DNCMAX(K)] is calculated after Botkin et al. (1972).

$$\begin{aligned} DNCMAX(K) = {} & G(I)*DBH(K)*\{1.0 - [137.*DBH(K) + B2(I)*DBH(K)**2 \qquad (18) \\ & - B3(I)*DBH(K)**3]/GR(I)\}/ \\ & [274. + 3.0*B2(I)*DBH(K) - 4.0*B3(I)*DBH(K)**2] \\ & \{I = 1,NSPEC;\ K = 1,NTOT[NTREES(I)]\} \end{aligned}$$

where

B2(I) and B3(I) are individual species growth factors,

G(I) is an individual species parameter specifying growth rate,

GR(I) is the product of maximum height and diameter according to Eq. (19).

$$GR(I) = 137. + \{0.25*[B2(I)**2/B3(I)]*[0.5*B2(I)/B3(I)]\} \quad (19)$$

(I = 1, NSPEC)

Botkin et al. (1972), Shugart and West (1977), and Pastor and Post (1985) estimate 'G(I)' by assuming that a tree reaches two thirds of its maximum dbh at one half of its maximum age. In the present model, this assumption was not implemented. Instead, 'G(I)' was determined in accordance to dbh measurements of yield tables and silvics literature. FORECE allows early tree growth to be accelerated. To this end, the user has to provide two different G-values in subroutine INPUT (parameters G1 and G2). 'G1' is the initial growth factor at age 0 that will decrease linearly to the level of 'G2' after 'DYG' years.

If air pollution impacts are simulated, the optimum diameter increment is reduced as a function of pollution intensity and species sensitivity. A maximum growth reduction [GI(I)] of 30% may occur. West et al. (1980) allowed a maximum reduction of 20%, and Dale and Gardner (1987) used values up to 35%. The following formula is used in FORECE:

$$GI(I) = SENS(I) * INT/C \qquad (I = 1,NSPEC) \qquad (20)$$

where

SENS(I) is the sensitivity of a species to a certain air pollutant on a scale between 0 and 3,

INT is the intensity of air pollution on a scale between 0 and 2,

C is a constant (set arbitrarily to a value of 20).

The procedure is a very simplified description of the complex biological mechanisms of pollution-induced changes in species-specific growth rates. The approach should be changed [according to the method described by Dale and Gardner (1987)] as soon as individual species survey data are available for the Swiss region (i.e., Swiss SANASILVA survey). FORECE assumes that growth reductions of different air pollutants are not multiplicative. Therefore, the air pollutant that causes the biggest growth reduction is chosen.

The DO-70 loop finally reduces the optimum diameter increment of each tree by the growth multiplier (GF) that is most limiting (Liebig 1840). The number of growth multipliers depends on the options chosen. In the default version there are four growth multipliers, including light (ALGF), soil moisture (SMGF), degree days (DEGDGF), and the competition factor (DCOMP). By choosing scenario 3, the growth multipliers for soil acidity, soil nitrogen, and soil water status may be added. The light multiplier (ALGF) for each tree is calculated using the vertical profile of leaf area through the canopy (parameter SUMLA). The amount of light filtering through the leaf area of all trees taller than a certain tree is calculated using Eq. (9). The parameter 'XLAI', however, is replaced by the parameter 'SUMLA.' Depending on the shade tolerance of a tree, the available light is transformed into the appropriate light multiplier 'ALGF' [Eqs. (21a) and (21b)]. The Formula is suggested by Botkin et al. (1972), who based their concept on data of Kramer and Kozlowski (1960).

$$ALGF = \begin{cases} 2.24 * \{1.0 - \exp[-1.136*(AL - 0.08)]\} & ISHAW = 5 \quad (21a) \\ 1 - \exp[-4.64*(AL - 0.05)] & ISHAW = 1 \quad (21b) \end{cases}$$

where

ISHAW is the parameter for shade tolerance on a qualitative scale from 1 (shade tolerant) to 5 (shade intolerant). The light multiplier for intermediate species is interpolated linearly.

Finally, the program determines if the actual diameter growth for any tree is greater than 0.3 mm or 10% of the maximum growth. If this growth increase cannot be maintained, the tree is flagged in the array 'NOGRO' as a slow-growing tree.

3.10 SUBROUTINE KILL

Subroutine KILL simulates the death of individual trees as a stochastic process with two independent components. The first component is an age-dependent killing process. It is assumed that only 1% of all seedlings of a species will reach their maximum age. According to the probability equation used (Botkin et al. 1972) a tree is killed as soon as the random number that is assigned to each tree every year is below '$\underline{\beta}$', where '$\underline{\beta}$' is calculated as

$$\beta = 4.605/\mathrm{AGEMX(I)} \qquad (\mathrm{I} = 1,\mathrm{NSPEC}). \qquad (22)$$

The age-independent mortality is determined by the actual increment of a tree. If a tree is growing less than the required amounts indicated in subroutine GROW (0.3 mm or 10% of the maximum increment), its probability of dying increases. After 2 consecutive years of slow growth, the tree has only a 1% chance of surviving the next 10 years.

3.11 SUBROUTINE OUTPUT

Subroutine OUTPUT is called in the first year of the succession and, subsequently, in a cycle of 'KPRNT' years. First, all variables that were calculated for the plot size of 1/12 ha are converted to values per hectare and are written on tape. The tape with identification No. 9 stores the current year, the individual species biomass data, the species-specific number of trees, total biomass, total number of trees, leaf area index, degree days, number of dry days, and actual evapotranspiration data. The tape with identification No. 12 stores the diameter distribution in every documentation year for each species. Later, these data are processed separately.

3.12 SUBROUTINES HUMINT AND CUT

Subroutine HUMINT simulates forest management influences representing standard Swiss practices. Two main forest types can be simulated (even-aged and uneven-aged stands), and up to five tree species can be specified as favored. To avoid favoritism toward species that are biologically atypical on the stand, an initial screening after 'ISCREN' years is done. The program checks the number of trees of each species that are within a certain dbh range (ALIM1, ALIM2). Each tree type that comprises at least 10% of all stems on the plot and is on the list of potentially favored species belongs to the privileged tree types. If none of the desired species reaches the 10% limit, the most frequent one will be favored even if it is not on the list of desired species. During the forest simulation additional screenings may occur, and other species have the chance to be selected if they fulfill the described requirements. If an uneven-aged forest type is anticipated, a new screening occurs if the percentage of harvested trees of the favorite species and of the valuable size is above a certain threshold [ALIM4, see subroutine INPUT, Eq. (1)]. If even-aged conditions are anticipated, a new screening takes place after a major tree removal.

Forest management interventions occur in cycles of 'ICYC1' years. However, at the beginning of the succession, they are suppressed during 'IFIRST' years. In an intervention year the actual dbh distribution is determined, as well as the average dbh of all trees on the plot. Depending on the forest type anticipated, the program calculates the number of trees that have to be cut to maintain either the theoretical dbh distribution (array IDIST; uneven-aged forests) or the density curve (array STEMDY; even-aged forests). The anticipated ratio between favored and unfavored trees in each dbh class (parameter ARATIO) controls the number of favorite and nonfavorite trees that have to be cut. At this point subroutine CUT is called to randomly remove the requested number of trees in each dbh class and to keep track of the cutting activities. The latter are reported for each plot. Subroutine

CUT is also called if a complete tree removal is requested in even-aged forest stands. This event is triggered as soon as enough trees reach a certain dbh.

Finally, requests for planting are issued if planting activities are necessary and planned. Planting of trees takes place in subroutine BIRTH. In even-aged stands, tree planting occurs after a complete removal of trees, whereas in uneven-aged forests, planting takes place after each management intervention and as long as the number of trees in the smallest dbh class (0-8 cm) does not fulfill the requirements of the theoretical dbh distribution function. The number of trees to be planted is calculated as the difference between the actual number of trees in the 0- to 8-cm class and the theoretical number. If, in uneven-aged forests, the theoretical number of young trees cannot be maintained during three management cycles, warning messages are issued and browsing is eliminated. After the fourth management cycle with an unsatisfying number of young trees, the theoretical dbh distribution function is adjusted. A 10% reduction occurs in each dbh class, and trees are cut accordingly.

3.13 SUBROUTINE DOCUM

Subroutine DOCUM documents several model processes, that is, human activities such as cutting and planting on each plot, factors that inhibited recruiting of new seedlings, and factors that limited growth. Also, the forest composition on each plot at the end of each simulation is given, including a dbh distribution for each species. Finally, the averaged forest composition of all plots is reported at the end of the simulation, including average biomass of each species over the whole time period. A complete listing of a plot documentation is given in Sect. 4.

3.14 SUBROUTINE ERR

This subroutine provides error checks, focusing mainly on mistakes encountered by exceeding array limits.

4. SAMPLE RUN

4.1 PRINTED OUTPUT

Since this is a technical manual for the forest simulator FORECE, only one model run is reproduced here to explain the main features of the simulator. Model verification and validation are not discussed in detail but are the subjects of subsequent reports. The example simulated was conducted with 50 plots for a 1200-year period without climatic change for a forest ecosystem with a moderate soil moisture status in the Swiss Midland (indicator value 5; meteorological station Bern, 570 m). No forest management is assumed, but the option "indicator values for temperature and temperature amplitude" is turned on. The input file of this run is documented in Appendix A together with the FORTRAN code of the program.

Tables 8a through g and 9 give a full documentation of the model output. Initially, control data are printed with information about the options and scenarios chosen (Tables 8a and 8b). Subsequently, the program documents several modeling processes for each plot, that is, human activities and information about limiting factors for tree recruitment and growth (Tables 8c and 8d).

The table "birth selection matrix for plot n" (Table 8c) indicates how often each environmental factor listed in the table head inhibited the recruitment of new seedlings of a specific species. The inhibition frequency is expressed in percent of all recruitment attempts. The abbreviations in the title head have the following meaning: 'CHOICE' indicates species that are excluded by the user. Other parameters show how often the average January temperature was too low for seedling recruitment ('JAN TMP') or how often light at the forest floor was insufficient ('LIGHT'). 'DEG DAYS,' 'FROST,' and 'BROWS,' indicate unsuccessful recruiting because of exceeded degree days tolerance and frost or browsing. 'TMP+TAMPL.' shows how often the mean annual temperature and temperature amplitude of the climatic station were too low to make establishment of new seedlings possible. This criterion is optional and represents the option "indicator values for temperature

Table 8a. Default output of the simulation model FORECE (50 low-elevation plots in the Swiss Midland, meteorological station Bern, no forest management)

```
                    *******************
                    *                 *
                    *  PROGRAM FORECE *
                    *                 *
                    *******************

FOREST SUCCESSION MODEL FOR SWISS AND CENTRAL EUROPEAN FORESTS
DEVELOPED BY FELIX KIENAST, OAK RIDGE NATIONAL LABORATORY,
ENVIRONMENTAL SCIENCES DIVISION, OAK RIDGE, TENNESSEE 37831, USA.
FINANCIAL CONTRACTS:- SWISS NATIONAL SCIENCE FOUNDATION
                      (GRANT NO. 84 ZH 32)
                    - MARTIN MARIETTA ENERGY SYSTEMS INC.
                      (SUBCONTRACTS 11X-57507V AND
                      32X-57507V)


CONTROL DATA:
-------------
PRINT INTERVAL:    5 NUMBER OF PLOTS:  50  NUMBER OF YEARS SIMULATED:  1200
PLOTS GENERATED OR NOT:  Y MAX. BIOMASS PER STAND (KG PER 1/12 HA): 45000.000
MAX. BIOMASS PER HA    (TONS)          :         540.000
START VALUES FOR RANDOM NUMBER GENERATOR: 73910   48206

SPECIES USED FOR MODELLING (Y); NOT USED (N):
  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
  Y  Y  Y  Y  Y  Y  Y  Y  N  Y  Y  Y  Y  Y  Y  Y  Y  Y  Y  Y  Y  Y  Y  Y  Y
 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
  Y  Y  Y  Y  Y  Y
SPECIES CONIFEROUS (C) OR DECIDUOUS (D):
  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
  C  C  C  C  C  C  C  C  C  D  D  D  D  D  D  D  D  D  D  D  D  D  D  D  D
 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
  D  D  D  D  D  D

BROWSING?  Y
FROST THRESHOLD VALUES (TEMPERATURE, DEGREES CELSIUS)
MARCH:   3.50  APRIL:   6.50  MAY:   9.50

SELECTED OPTIONS:
-----------------
OPTION <OPTIMUM INFORMATION AFTER ELLENBERG (1978)>:  N
OPTION <INDICATOR VALUES FOR TEMP. AND TAMPL>: Y


SCENARIO INFORMATIONS:
----------------------
SCENARIO 1 (CLIMATIC CHANGE):        MANDATORY
SAME CLIMATIC SIMULATION IN ALL PLOTS?  N
NUMBER OF INTERPOLATION POINTS:    2
YEARS IN WHICH CLIMATIC CONDITIONS CHANGE:
   0. 1200.     0.     0.     0.     0.     0.     0.     0.     0.

  1. BRACKET YEAR FOR CLIMATE CHANGE
```

	J	F	M	A	M	J	J	A	S	O	N	D
TEMP (C)	-1.1	0.5	4.2	8.1	12.6	15.8	17.7	17.0	13.7	8.5	3.4	0.0
STND DEV	2.2	2.6	1.7	1.6	1.5	1.4	1.6	1.4	1.6	1.5	1.5	1.9
PPT (CM)	5.8	5.5	6.5	7.8	9.8	11.7	11.4	11.4	8.9	7.2	7.5	6.5
STND DEV	3.3	3.9	3.7	3.7	3.6	4.1	5.3	5.3	4.5	4.7	4.9	4.0

Table 8b. Default output of the simulation model FORECE (50 low-elevation plots in the Swiss Midland, meteorological station Bern, no forest management)

2. BRACKET YEAR FOR CLIMATE CHANGE

	J	F	M	A	M	J	J	A	S	O	N	D
TEMP (C)	-1.1	0.5	4.2	8.1	12.6	15.8	17.7	17.0	13.7	8.5	3.4	0.0
STND DEV	2.2	2.6	1.7	1.6	1.5	1.4	1.6	1.4	1.6	1.5	1.5	1.9
PPT (CM)	5.8	5.5	6.5	7.8	9.8	11.7	11.4	11.4	8.9	7.2	7.5	6.5
STND DEV	3.3	3.9	3.7	3.7	3.6	4.1	5.3	5.3	4.5	4.7	4.9	4.0

```
SCENARIO 2 (AIR POLLUTION EFFECTS) ON OR OFF:  N
FLUORIDES: N STARTYR=   0 INT.=0 BREAK=   0 INT.=0 ENDYR=   0 INT.=0
SO2      : N STARTYR=   0 INT.=0 BREAK=   0 INT.=0 ENDYR=   0 INT.=0
NO2      : N STARTYR=   0 INT.=0 BREAK=   0 INT.=0 ENDYR=   0 INT.=0
NO3      : N STARTYR=   0 INT.=0 BREAK=   0 INT.=0 ENDYR=   0 INT.=0

SCENARIO 3 (SOIL CONDITIONS) ON OR OFF:  Y
PH       : N STARTYR=   0 INT.=3 BREAK= 100 INT.=3 ENDYR= 250 INT.=3
NITROGEN : N STARTYR=   0 INT.=0 BREAK=   0 INT.=0 ENDYR=   0 INT.=0
WATERCONT: Y STARTYR=   0 INT.=5 BREAK= 100 INT.=5 ENDYR=1200 INT.=5

SCENARIO 4 (HUMAN INTERVENTION) ON OR OFF: N
FOREST TYPE DESIRED: 2  (1: UNEVEN AGED 2: EVEN AGED
UNEVEN-AGED FORESTS: DIAMETER DISTRIBUTION FUNCTION
DBH (CM)    0- 8   8-16  16-24  24-32  32-48  48-72    >72
N (TREES)   300     20      8      4      4      3      2
EVEN-AGED FORESTS: STEM DENSITY IN RELATION TO THE MEAN
DBH-VALUE OF THE STAND (VALUES BETWEEN THE LIMITS WILL BE
INTERPOLATED:
DBH (CM)         1      8     16      24      32     48     >72
STEMS         800.   300.   120.     60.     30.    15.      5.
BOTH FOREST TYPES: PERCENTAGE OF TREES OF THE FAVORED
SPECIES IN EACH DBH-CLASS:
DBH (CM)       0- 8   8-16   16-24  24-32  32-48  48-72    >72
% OF TREES      65.    80.     80.    80.    80.    80.    90.

INGROWTH METHOD DESIRED: 2
(1: ONLY NATURALLY; 2: NATURALLY AND PLANTED
SPECIES AND QUANTITIES TO BE PLANTED (IN UNEVEN AGED STANDS
THE REQUIRED QUANTITIES ARE CALCULATED AUTOMATICALLY):
SPEC QUANT  SPEC QUANT  SPEC QUANT  SPEC QUANT  SPEC QUANT
   2  800      0    0      0     0     0     0     0     0
NUMBER OF SPECIES FAVORED: 1
FAVORED SPECIES:     2   0   0   0   0

ADDITIONAL INFORMATION:
UNEVEN-AGED STANDS: SCREENING THRESHOLD (YIELD OF FAVORITE TREES):       5.00
EVEN-AGED STANDS:   NUMBER OF MERCHANTABLE TREES BIGGER THAN DBH1:          5
                    DBH1                                                50.00
                    IDBH2                                                   0
BOTH FOREST TYPES:  INITIAL SCREENING (YEARS)                               3
                    REMOVAL CYCLE FOR WOOD (YEARS)                         10
                    NUMBER OF YEARS WITHOUT ANY FOREST MANAGEMENT           3
                    DBH LIMITS FOR SCREENING                  0.00      24.00
                    DBH OF TREES CONSIDERED MERCHANTABLE                50.00


ADDITIONAL INFORMATION:
----------------------
LATITUDE= 46.9    LONGITUDE=  7.4   GROWING SEASON BEGINS ON DAY 120.0
                                    AND ENDS ON DAY 273.0
FIELD CAPACITY (CM)= 30.0  WILTING POINT = 20.0
```

Table 8c. Default output of the simulation model FORECE (50 low-elevation plots in the Swiss Midland, meteorological station Bern, no forest management)

HUMAN ACTIVITIES ON PLOT 1

NO HUMAN INTERVENTION TOOK PLACE

BIRTH SELECTION MATRIX FOR PLOT 1

REJECTION FREQUENCIES OF DIFFERENT CRITERIONS.

SPECIES	CHOICE	JAN TMP	LIGHT	DEG DAYS	FROST	BROWS	TMP+T AMPL. OPTION	OPTIMUM INFO. OPTION	ALL
ABIES ALBA	0	0	44	0	12	33	0	0	67
PICEA ABIES	0	0	72	0	9	17	0	0	79
PINUS SYLVESTRIS	0	0	89	0	3	17	0	0	91
PINUS CEMBRA	0	0	72	100	3	33	0	0	100
LARIX DECIDUA	0	0	89	0	9	17	0	0	91
PINUS STROBUS	0	0	72	32	9	17	100	0	100
PINUS MUGO	0	0	89	57	3	17	0	0	100
TAXUS BACCATA	0	0	44	0	7	33	0	0	66
PSEUDOTSUGA MENZIESII	100	0	44	0	7	0	0	0	100
FAGUS SYLVATICA	0	0	44	0	15	33	0	0	68
QUERCUS ROBUR	0	0	89	0	9	17	0	0	91
QUERCUS PETREA	0	0	87	0	9	17	0	0	89
QUERCUS PUBESCENS	0	0	89	0	12	17	100	0	100
CARPINUS BETULUS	0	0	44	0	9	33	0	0	66
ACER PSEUDOPLATANUS	0	0	44	0	9	0	0	0	49
ACER PLATANOIDES	0	0	44	0	9	0	0	0	49
ACER CAMPESTRE	0	0	72	0	9	0	0	0	74
FRAXINUS EXCELSIOR	0	0	44	0	15	17	0	0	59
ULMUS SCABRA	0	0	44	0	7	0	0	0	47
TILIA CORDATA	0	0	72	0	9	17	0	0	79
TILIA PLATYPHYLLOS	0	0	44	0	9	17	0	0	57
BETULA VERRUCOSA	0	0	89	0	3	0	0	0	89
ALNUS INCANA	0	0	87	0	7	17	0	0	89
ALNUS GLUTINOSA	0	0	72	0	9	17	0	0	79
ALNUS VIRIDIS	0	0	89	100	7	17	0	0	100
POPULUS TREMULA	0	0	87	0	3	33	0	0	92
POPULUS NIGRA	0	0	72	0	7	33	100	0	100
SALIX ALBA	0	0	72	0	7	0	0	0	73
SORBUS ARIA	0	0	87	0	9	17	0	0	89
SORBUS AUCUPARIA	0	0	87	0	3	17	0	0	89
CASTANEA SATIVA	0	0	72	0	15	17	100	0	100

Table 8d. Default output of the simulation model FORECE (50 low-elevation plots in the Swiss Midland, meteorological station Bern, no forest management)

LIMITING FACTOR MATRIX FOR PLOT 1

FREQUENCIES OF THE LIMITING FACTORS.

SPECIES	LIGHT	SOIL MOIS	DEG DAYS	DCOMP	SOIL PH (INDIC.	SOIL N VALUE	SOIL MOIS OPTIONS)	G-RED AIRP.	DMAX	D
ABIES ALBA	78	3	0	6	0	0	13	0	0.310	0.105
PICEA ABIES	68	8	20	4	0	0	0	0	0.435	0.129
PINUS SYLVESTRIS	24	0	0	0	0	0	76	0	0.333	0.038
PINUS CEMBRA	0	0	0	0	0	0	0	0	0.000	0.000
LARIX DECIDUA	37	7	19	0	0	0	36	0	0.454	0.169
PINUS STROBUS	0	0	0	0	0	0	0	0	0.000	0.000
PINUS MUGO	0	0	0	0	0	0	0	0	0.000	0.000
TAXUS BACCATA	96	1	3	0	0	0	0	0	0.097	0.024
PSEUDOTSUGA MENZIESII	0	0	0	0	0	0	0	0	0.000	0.000
FAGUS SYLVATICA	76	5	3	16	0	0	0	0	0.695	0.244
QUERCUS ROBUR	47	0	0	0	0	0	53	0	0.771	0.312
QUERCUS PETREA	21	5	0	0	0	0	75	0	0.501	0.055
QUERCUS PUBESCENS	0	0	0	0	0	0	0	0	0.000	0.000
CARPINUS BETULUS	86	3	9	2	0	0	0	0	0.624	0.168
ACER PSEUDOPLATANUS	91	2	0	0	0	0	7	0	0.556	0.118
ACER PLATANOIDES	86	2	10	2	0	0	0	0	0.563	0.163
ACER CAMPESTRE	82	0	18	0	0	0	0	0	0.495	0.151
FRAXINUS EXCELSIOR	86	4	0	0	0	0	9	0	0.639	0.136
ULMUS SCABRA	83	3	3	2	0	0	10	0	0.286	0.083
TILIA CORDATA	83	3	9	0	0	0	5	0	0.606	0.141
TILIA PLATYPHYLLOS	92	2	6	0	0	0	0	0	0.529	0.106
BETULA VERRUCOSA	14	4	0	0	0	0	83	0	0.486	0.056
ALNUS INCANA	13	12	0	0	0	0	75	0	0.422	0.045
ALNUS GLUTINOSA	0	7	0	0	0	0	93	0	0.331	0.000
ALNUS VIRIDIS	0	0	0	0	0	0	0	0	0.000	0.000
POPULUS TREMULA	53	4	15	28	0	0	0	0	1.318	0.666
POPULUS NIGRA	0	0	0	0	0	0	0	0	0.000	0.000
SALIX ALBA	0	5	0	0	0	0	95	0	0.537	0.006
SORBUS ARIA	17	0	0	0	0	0	83	0	0.127	0.016
SORBUS AUCUPARIA	14	0	0	0	0	0	86	0	0.275	0.034
CASTANEA SATIVA	0	0	0	0	0	0	0	0	0.000	0.000

Table 8e. Default output of the simulation model FORECE (50 low-elevation plots in the Swiss Midland, meteorological station Bern, no forest management)

FOREST COMPOSITION AT THE END OF SIMULATION OF PLOT 1 (1200 YEARS)

LEAF AREA INDEX (SQM/SQM):	11.05
TOTAL NUMBER OF TREES PER HA:	324.00
TOTAL ABOVEGROUND BIOMASS (DRY WEIGHT, T/HA):	243.26

SPECIES SPECIFIC VALUES:

SPE-CIES	BIOMASS (T/HA,DRY)	NO.OF TREES P.HA	DBH-CLASSES (CM) 0 - 8	8 - 16	16 - 24	24 - 32	32 - 40	40 - 48	48 - 56	56 - 64	64 - 72	72 - 80	80 - 88	88 - 96	96 - 104	> 104
1	14.99	96	0	36	48	12	0	0	0	0	0	0	0	0	0	0
2	8.99	24	0	0	0	24	0	0	0	0	0	0	0	0	0	0
10	118.04	48	12	0	12	0	0	0	0	0	0	12	0	12	0	0
16	61.98	108	0	0	24	24	36	12	12	0	0	0	0	0	0	0
18	31.45	12	0	0	0	0	0	0	0	0	12	0	0	0	0	0
19	7.80	36	0	0	24	12	0	0	0	0	0	0	0	0	0	0

SPECIES IDENTIFICATION:

NO.	NAME
1	ABIES ALBA
2	PICEA ABIES
10	FAGUS SYLVATICA
16	ACER PLATANOIDES
18	FRAXINUS EXCELSIOR
19	ULMUS SCABRA

AVERAGED FOREST COMPOSITION (50 PLOTS) AFTER 1200 YEARS

DEGREE OF FREEDOM:	49	
LEAF AREA INDEX (SQM/SQM):	10.06 +-	0.29
TOTAL NUMBER OF TREES PER HECTARE:	1345.92 +-	236.52
TOTAL ABOVEGROUND BIOMASS (DRY WEIGHT,T/HA)	245.72 +-	24.03

SPECIES SPECIFIC VALUES:

SPECIES	BIOMASS (T/HA,DRY)	95% CONF	NO.OF TREES	95% CONF.	DBH-CLASSES (CM) 0 - 8	95% CONF	8 - 16	95% CONF
ABIES ALBA	69.25	16.62	144.	23.45	88	23.7	19	7.6
PICEA ABIES	11.04	5.84	39.	20.10	28	19.1	5	4.0
TAXUS BACCATA	0.07	0.00	84.	30.34	84	30.3	0	0.0
FAGUS SYLVATICA	58.32	20.29	144.	30.34	86	23.5	26	9.1
QUERCUS ROBUR	1.60	3.27	1.	2.45	0	0.0	0	0.0
CARPINUS BETULUS	1.78	1.15	51.	12.62	42	11.9	6	3.7
ACER PSEUDOPLATANUS	22.97	16.73	157.	45.93	126	44.5	19	8.5
ACER PLATANOIDES	42.94	11.61	289.	55.69	212	54.0	41	15.7
ACER CAMPESTRE	0.37	0.47	26.	12.83	24	12.6	2	2.4
FRAXINUS EXCELSIOR	6.58	5.43	72.	18.98	56	17.1	10	4.9
ULMUS SCABRA	7.20	2.22	206.	52.19	162	48.1	30	16.7
TILIA CORDATA	0.21	0.19	34.	18.59	32	18.2	1	1.6
TILIA PLATYPHYLLOS	23.40	18.89	95.	.30.74	81	28.3	7	4.7
ALNUS INCANA	0.00	0.00	0.	0.49	0	0.5	0	0.0
ALNUS GLUTINOSA	0.00	0.00	1.	1.44	1	1.4	0	0.0
SALIX ALBA	0.00	0.00	2.	2.21	2	2.2	0	0.0

Table 8f. Default output of the simulation model FORECE (50 low-elevation plots in the Swiss Midland, meteorological station Bern, no forest management)

SPECIES	DBH-CLASSES (CM) 16 - 24	95% CONF	24 - 32	95% CONF	32 - 40	95% CONF	40 - 48	95% CONF	48 - 56	95% CONF
ABIES ALBA	8	4.0	6	3.2	6	4.3	4	2.7	2	1.3
PICEA ABIES	1	1.4	2	2.2	1	1.1	0	0.5	1	1.2
TAXUS BACCATA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
FAGUS SYLVATICA	10	4.1	5	3.2	5	3.5	2	1.5	2	1.4
QUERCUS ROBUR	0	0.0	1	1.5	0	0.0	0	0.0	0	0.0
CARPINUS BETULUS	1	1.3	1	0.9	0	0.5	0	0.5	0	0.0
ACER PSEUDOPLATANUS	5	3.6	2	1.9	2	1.9	1	1.2	0	0.5
ACER PLATANOIDES	12	6.0	5	3.4	5	2.7	5	2.3	3	2.0
ACER CAMPESTRE	0	0.0	0	0.0	0	0.0	0	0.5	0	0.0
FRAXINUS EXCELSIOR	2	1.5	1	0.8	1	1.3	0	0.7	0	0.0
ULMUS SCABRA	8	5.2	3	1.6	2	1.9	0	0.7	0	0.7
TILIA CORDATA	1	1.5	0	0.0	0	0.0	0	0.0	0	0.0
TILIA PLATYPHYLLOS	3	2.8	0	0.7	0	1.0	0	0.5	0	0.0
ALNUS INCANA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
ALNUS GLUTINOSA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
SALIX ALBA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

SPECIES	DBH-CLASSES (CM) 56 - 64	95% CONF	64 - 72	95% CONF	72 - 80	95% CONF	80 - 88	95% CONF	88 - 96	95% CONF
ABIES ALBA	1	1.1	2	1.6	3	2.3	1	0.8	0	0.7
PICEA ABIES	0	0.7	0	0.7	0	0.0	0	0.7	0	0.7
TAXUS BACCATA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
FAGUS SYLVATICA	1	1.1	1	0.9	1	1.1	1	0.9	1	1.3
QUERCUS ROBUR	0	0.0	0	1.0	0	0.0	0	0.0	0	0.0
CARPINUS BETULUS	0	0.5	0	0.0	0	0.0	0	0.0	0	0.0
ACER PSEUDOPLATANUS	0	0.0	0	0.0	0	0.5	0	0.0	0	0.5
ACER PLATANOIDES	3	1.6	1	1.3	1	0.8	1	1.1	1	0.9
ACER CAMPESTRE	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
FRAXINUS EXCELSIOR	0	0.7	0	0.5	0	0.0	0	0.0	0	0.0
ULMUS SCABRA	0	0.7	0	0.0	0	0.0	0	0.0	0	0.0
TILIA CORDATA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
TILIA PLATYPHYLLOS	0	0.0	0	0.5	0	0.5	0	0.7	0	0.0
ALNUS INCANA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
ALNUS GLUTINOSA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
SALIX ALBA	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

SPECIES	DBH-CLASSES (CM) 96 - 104	95% CONF	> 104	95% CONF
ABIES ALBA	1	0.9	1	1.1
PICEA ABIES	0	0.0	0	0.0
TAXUS BACCATA	0	0.0	0	0.0
FAGUS SYLVATICA	0	0.7	1	1.1
QUERCUS ROBUR	0	0.0	0	0.0
CARPINUS BETULUS	0	0.0	0	0.0
ACER PSEUDOPLATANUS	0	0.0	1	1.1
ACER PLATANOIDES	0	0.0	0	0.0
ACER CAMPESTRE	0	0.0	0	0.0
FRAXINUS EXCELSIOR	0	0.0	0	0.5
ULMUS SCABRA	0	0.0	0	0.0
TILIA CORDATA	0	0.0	0	0.0
TILIA PLATYPHYLLOS	1	0.8	1	0.8
ALNUS INCANA	0	0.0	0	0.0
ALNUS GLUTINOSA	0	0.0	0	0.0
SALIX ALBA	0	0.0	0	0.0

Table 8g. Default output of the simulation model FORECE (50 low-elevation plots in the Swiss Midland, meteorological station Bern, no forest management)

AVERAGED BIOMASS (T/(HA*PLOT*YR)) FOR EACH SPECIES

SPECIES	AVG. BIOMASS
ABIES ALBA	33.74
PICEA ABIES	20.19
PINUS SYLVESTRIS	0.00
PINUS CEMBRA	0.00
LARIX DECIDUA	0.03
PINUS STROBUS	0.00
PINUS MUGO	0.00
TAXUS BACCATA	0.05
PSEUDOTSUGA MENZIESII	0.00
FAGUS SYLVATICA	83.38
QUERCUS ROBUR	0.18
QUERCUS PETREA	0.01
QUERCUS PUBESCENS	0.00
CARPINUS BETULUS	2.62
ACER PSEUDOPLATANUS	20.21
ACER PLATANOIDES	47.46
ACER CAMPESTRE	0.25
FRAXINUS EXCELSIOR	5.56
ULMUS SCABRA	6.10
TILIA CORDATA	1.08
TILIA PLATYPHYLLOS	14.13
BETULA VERRUCOSA	0.01
ALNUS INCANA	0.00
ALNUS GLUTINOSA	0.00
ALNUS VIRIDIS	0.00
POPULUS TREMULA	6.67
POPULUS NIGRA	0.00
SALIX ALBA	0.00
SORBUS ARIA	0.00
SORBUS AUCUPARIA	0.00
CASTANEA SATIVA	0.00

Table 9. Supplemental output of the simulation model FORECE if forest management is supposed

HUMAN ACTIVITIES ON PLOT 1

EVEN-AGED FOREST STAND ANTICIPATED

A) CUTTING AND FAVORING ACTIVITIES:

FAVORED SPECIES	NO. OF TREES ANTIC.	START YEAR	END YEAR	NUMBER OF TREES THAT WERE CUT IN THE LISTED DBH-CLASSES 0 - 8	8 - 16	16 - 24	24 - 32	32 - 48	48 - 72	>72	VALUABLE TREES DBH> 50.0 CUT	DIED
2	--	3	180	424	33	0	0	4	4	0	4	0
2	--	183	337	472	27	0	0	6	6	0	5	0
2	--	340	501	452	30	0	0	3	7	0	6	0
2	--	504	664	408	19	0	0	4	7	0	5	0
2	--	667	836	338	27	0	0	4	8	0	6	0
2	--	839	1004	442	30	0	0	6	5	0	5	0
2	--	1007	1189	440	34	0	0	4	4	0	4	0
2	--	1192	1199	201	0	0	0	0	0	0	0	0

NON-FAVORED SPECIES	NO. OF TREES ANTIC.	START YEAR	END YEAR	NUMBER OF TREES THAT WERE CUT IN THE LISTED DBH-CLASSES 0 - 8	8 - 16	16 - 24	24 - 32	32 - 48	48 - 72	>72	VALUABLE TREES DBH> 50.0 CUT	DIED
DIV	--	3	180	10	3	0	0	0	0	2	2	2
DIV	--	183	337	0	5	0	0	0	0	0	0	2
DIV	--	340	501	19	3	0	0	0	0	0	0	0
DIV	--	504	664	10	1	0	1	0	0	0	0	0
DIV	--	667	836	0	0	0	0	0	0	0	0	0
DIV	--	839	1004	11	3	0	0	0	0	0	0	1
DIV	--	1007	1189	107	8	1	0	0	0	1	1	4
DIV	--	1192	1199	0	1	0	0	0	0	0	0	0

B) PLANTING ACTIVITIES:

SPECIES	YEAR OF PLANTING	NUMBER OF SEEDLINGS
2	1	800
2	181	800
2	338	800
2	502	800
2	665	800
2	837	800
2	1005	800
2	1190	800

and temperature amplitude" (see subroutines INPUT and BIRTH). 'OPTIMUM INFO,' which documents how often a species' chance of being selected was increased, is also optional and represents the option "optimum information after Ellenberg (1978)" (see subroutines INPUT and BIRTH). Finally, the column 'ALL' summarizes the entire process of tree establishment and indicates how many times the birth process for a certain species was inhibited for whatever reason. Since several parameters may be unfavorable for seedling, the column 'ALL' is not simply the sum of all other columns.

The table "Limiting factor matrix for plot n" (Table 8d) gives an overall picture of the minimum factors for tree growth. The percent values indicate the number of cases the different parameters listed were the smallest growth multiplier and therefore the limiting factors. 'LIGHT,' 'SOIL MOIS,' 'DEG DAYS,' and 'DCOMP' stand for the light growth multiplier (ALGF, subroutine GROW), the soil moisture growth multiplier (SMGF, subroutine GMULT), the degree day growth multiplier (DEGDGF, subroutine GMULT), and the nutrient and competition growth multiplier (DCOMP, subroutine GROW). The next four columns provide evidence about additional limiting factors, if the additional scenarios 2 or 3 are turned on. 'SOIL PH' documents the influence of the indicator value 'soil acidity' (IACID) and the corresponding growth multiplier, whereas 'SOIL N' and 'SOIL MOIS' represent the indicator values 'soil nitrogen content' (INIT) and 'soil moisture' (IMST1, IMST2) and their growth multipliers. The column 'G-RED AIRP.' indicates the average reduction of the G-value because of air pollution influences. Finally, the averaged maximum diameter increment of each species through the entire simulation is given (column DMAX), as well as the averaged actual diameter increment (column D).

The table "Forest composition at the end of simulation of plot n" (Table 8e) provides information about the species composition in the last year of the simulation on each plot. The species are listed according to their identification numbers.

All tables designed on a plot-by-plot basis are subsequently repeated. At the very end, the program provides information about the averaged forest composition of all plots ("Averaged forest composition (n plots) after nn years"; Tables 8e, and 8f). Each species is listed with its biomass and the corresponding dbh distribution, including the 95% confidence intervals. The remaining table (Table 8g) contains the averaged biomass over all plots and years and helps to assess the most important species of the simulated forest ecosystem.

Since the forest succession presented here does not simulate human intervention (scenario 4 is turned off), the table describing planting and cutting activities does not appear. Instead, the sentence is printed "No human intervention took place (Table 8c)." However, in order to provide a complete listing of a possible output, Table 9 gives an example of the table "Human activities on plot n" if the simulation were run with the human intervention scenario reproduced in Table 8b. The documentation table shows the forest type desired and summarizes cutting activities. Favored and nonfavored species are presented separately. Each species that was favored during a certain time is listed with the time span during which favoritism occurred (including the number of trees that were cut during this period). Also, the number of trees of merchantable size (parameter ALIM3) that were cut or died is recorded. For uneven-aged stands, the documentation indicates how many trees of merchantable size were anticipated. This column remains blank for even-aged forest stands. Cutting activities of the nonfavored tree species are subsequently summarized. Information about cutting activities is followed by a summary of planting attempts. Each species that was planted is listed, including the number of seedlings and the year in which this intervention took place.

4.2 PLOTTED OUTPUT

Data written on tape (see subroutine OUTPUT) are normally processed with separate graphics programs. The drawings produced may vary, depending on the model application and the graphics software available. As a consequence, no graphics program is described in this report. However, a series of routinely generated plots (Figs. 4 through 11) are reproduced to facilitate the interpretation of the forest simulation previously described.

Figure 4 shows the simulated average number of degree days and the number of dry days on the 50 low-elevation sites in the Swiss Midland (moderate soil-moisture status, meteorological station Bern, 1200 simulation years). Only a marginal number of days of the growing season show an insufficient water supply. Therefore, a soil moisture index of 5 (Ellenberg 1978) seems to be appropriate for this soil. Figure 5 gives an overall picture of the biomass for the major species. The confidence limits allow one to determine which species are significantly present on the 50 plots. As long as the lower limit is zero, there is no statistical evidence that the species is part of the plant succession. Figure 6 is the equivalent graph to Fig. 5 but shows the number of trees for each species instead of the biomass. The biomass composite plots (Figs. 7 and 8) are useful for assessing the successional interactions between the different species (Shugart 1984). The importance of each species is either expressed as a percentage of the whole biomass (Fig. 7) or in absolute values (Fig. 8). Figures 9 through 11 show total biomass, number of stems, and leaf area index as a function of time.

4.3 INTERPRETATION

According to Braun-Blanquet (1932), Ellenberg (1978), Firbas, (1952), Lüdi (1935), Stamm (1938), and Schmid (1949), the natural vegetation of the simulated low-elevation forest ecosystem in the Swiss Midland should be dominated by European beech (Fig. 12). The simulation of 50 plots confirms this hypothesis and shows a biomass dominance of beech with a significant percentage of silver fir (*Abies alba*), Norway spruce (*Picea abies*), and maple (*Acer platanoides* and *Acer pseudoplatanus*). The species composition through time can be divided into four main periods, that is, 0 to 150 years, 150 to 400

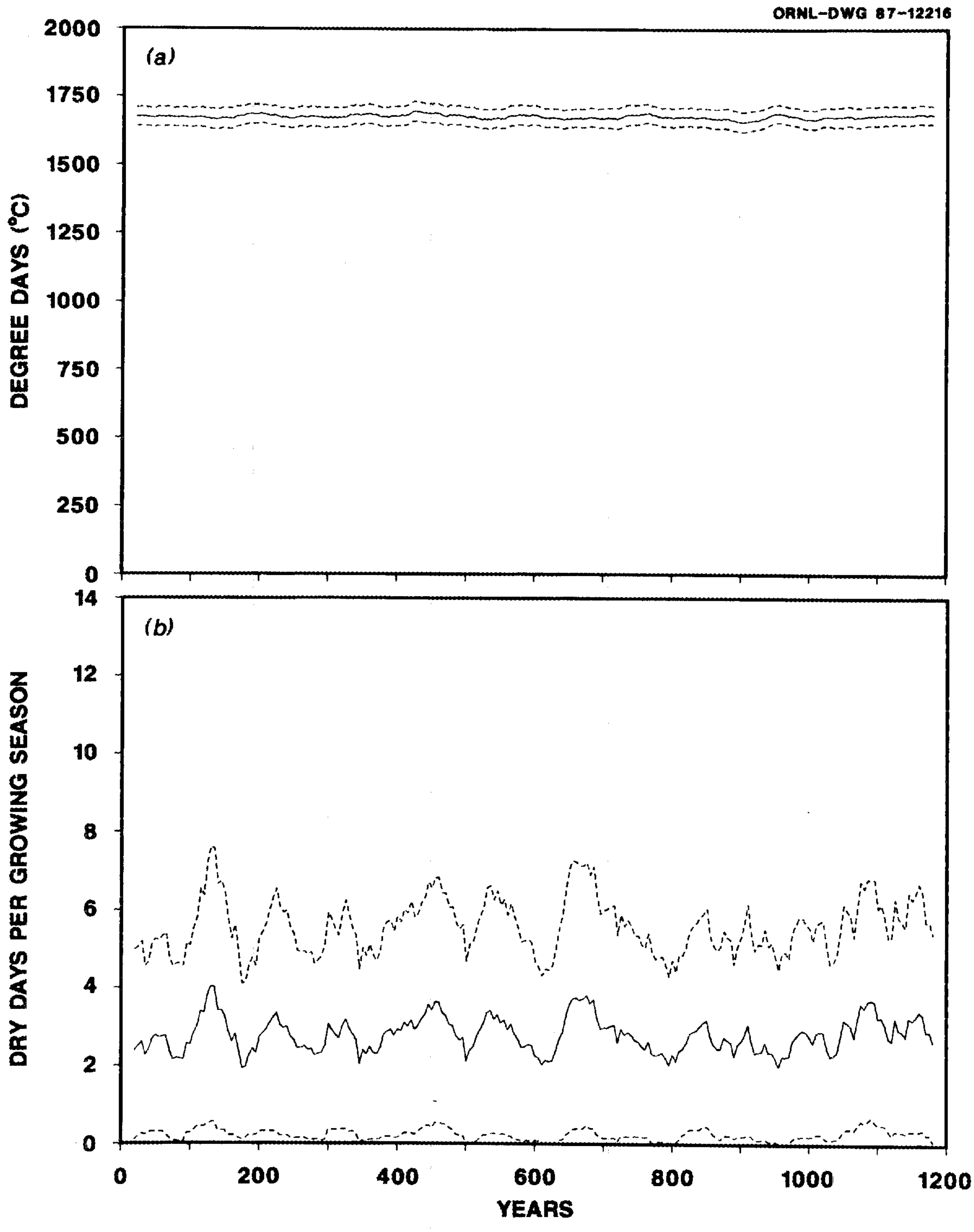

Fig. 4. Simulated degree days and number of dry days per growing season of 50 low-elevation plots in the Swiss Midland (meteorological station Bern; moderate soil moisture status; no forest management). For both parameters, the solid line represents a 9-point moving average of 50 plots (data points in intervals of 5 years). The dashed lines show the upper and the lower 95% confidence limit.

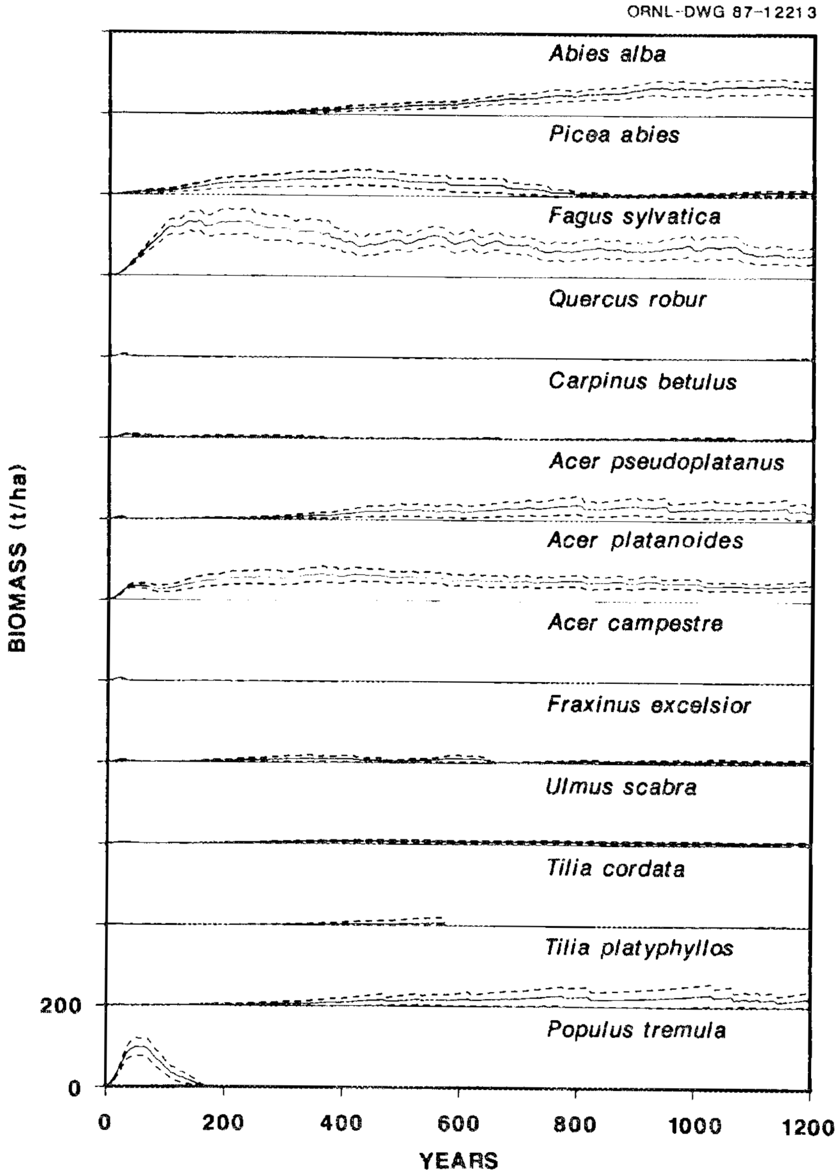

Fig. 5. Simulated biomass through time for the major species of 50 low-elevation plots in the Swiss Midland (meteorological station Bern; moderate soil moisture status; no forest management). The solid line represents the average biomass of 50 plots in intervals of 5 years (no moving average). The dashed lines show the upper and the lower 95% confidence limit. The scaling is equal for all species, as indicated for aspen (Populus tremula).

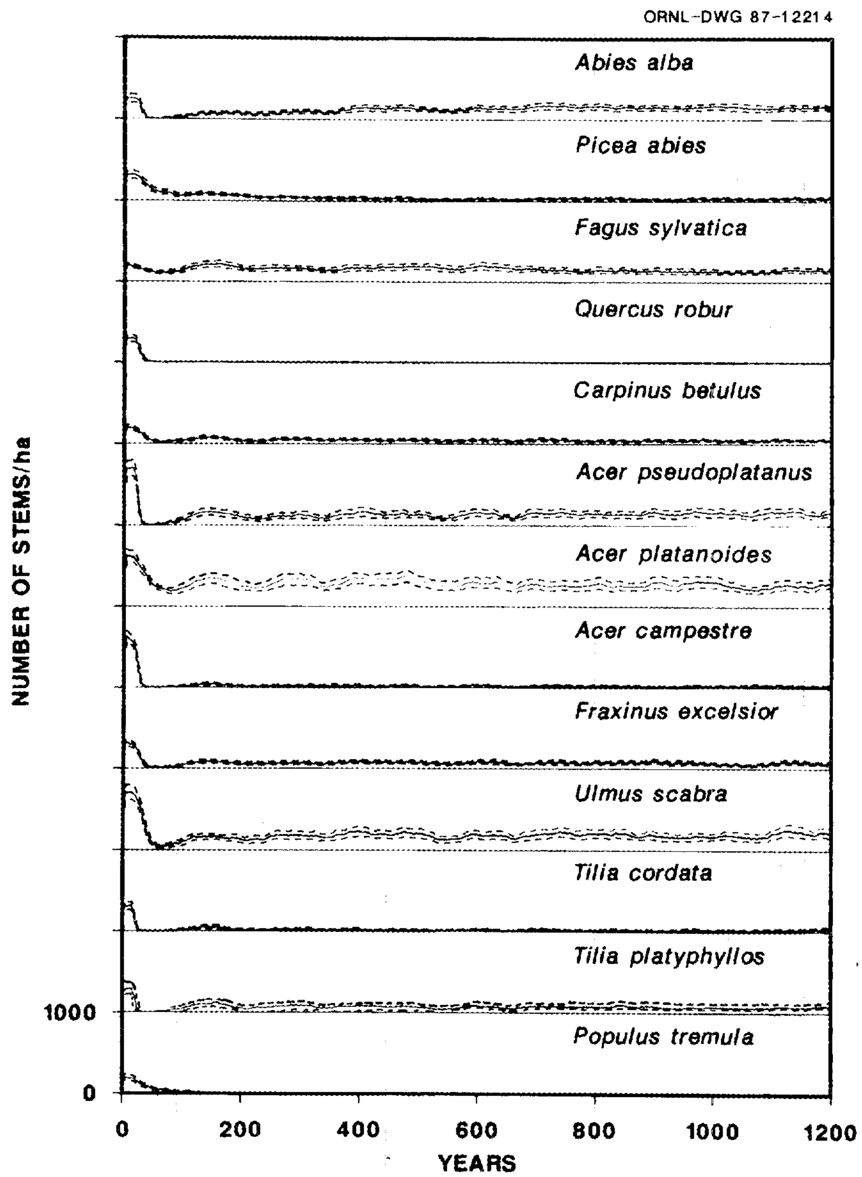

Fig. 6. Simulated absolute number of stems through time for the major species of 50 low-elevation plots in the Swiss Midland (see Fig. 5).

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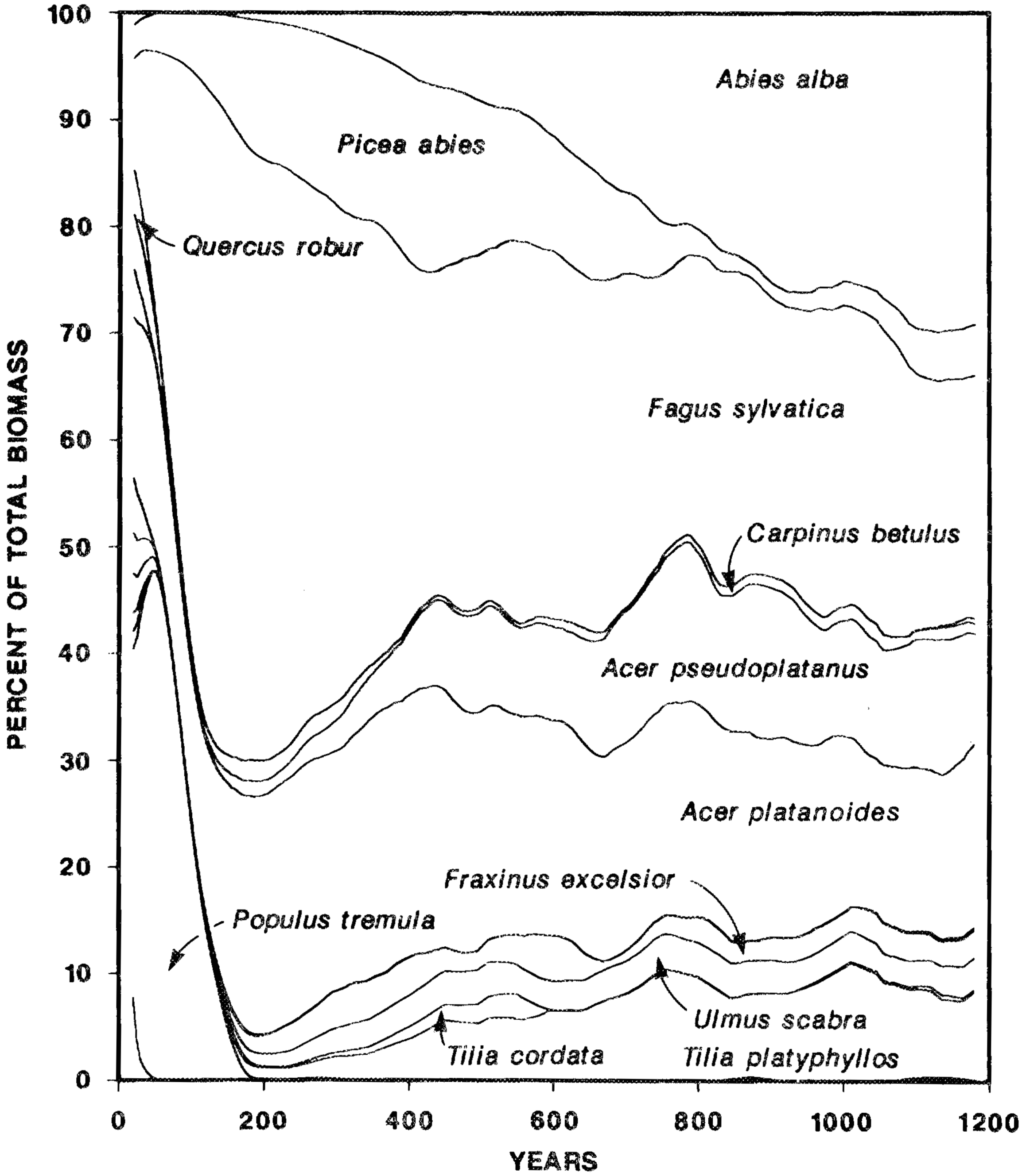

Fig. 7. Simulated percentage of total biomass through time for the major species of 50 low-elevation plots in the Swiss Midland (meteorological station Bern; moderate soil moisture status; no forest management). The solid lines represent a 9-point moving average of 50 plots (data points in intervals of 5 years).

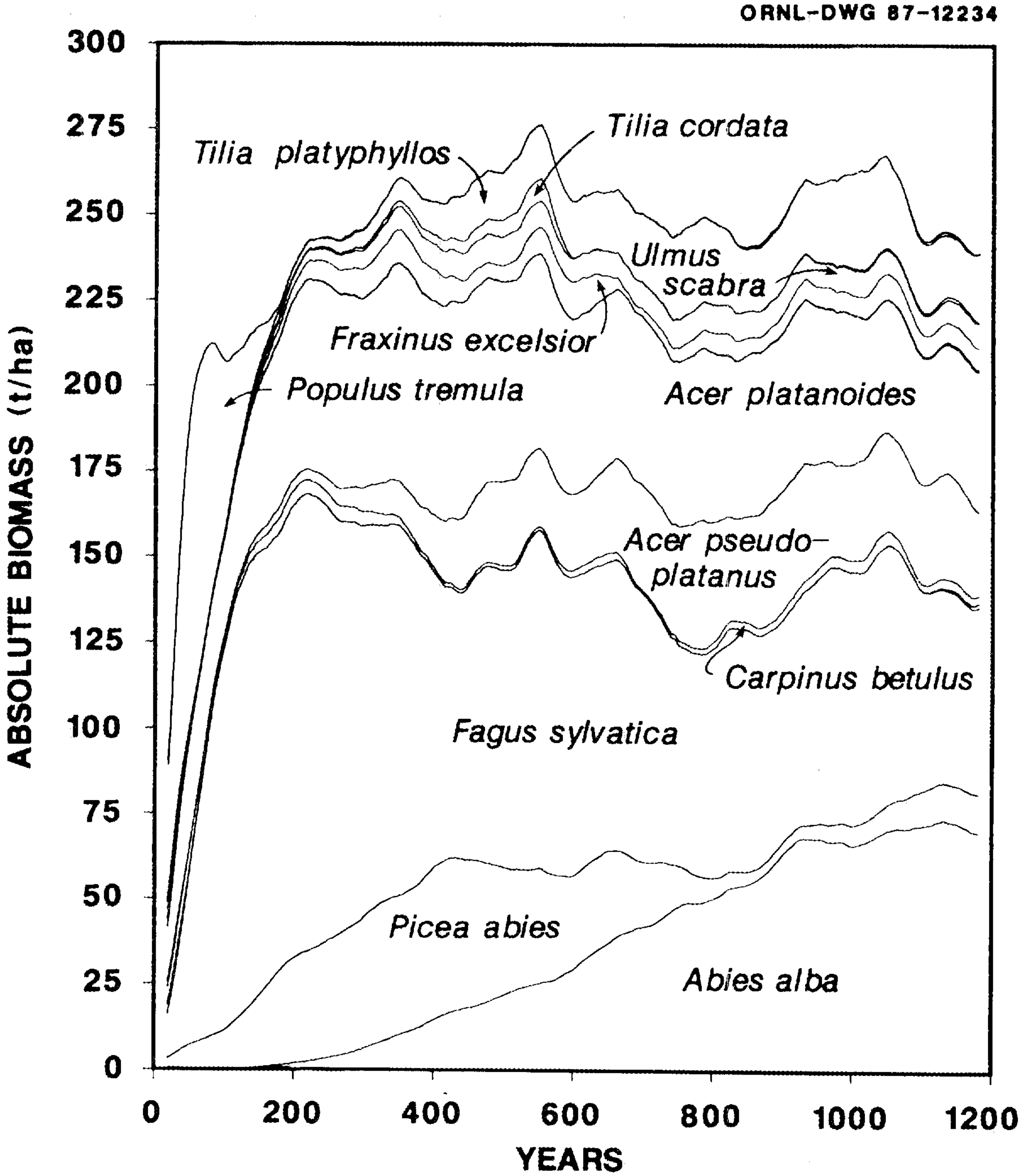

Fig. 8. Simulated absolute biomass through time for the major species of 50 low-elevation plots in the Swiss Midland (meteorological station Bern; moderate soil moisture status; no forest management). The solid lines represent a 9-point moving average of 50 plots (data points in intervals of 5 years).

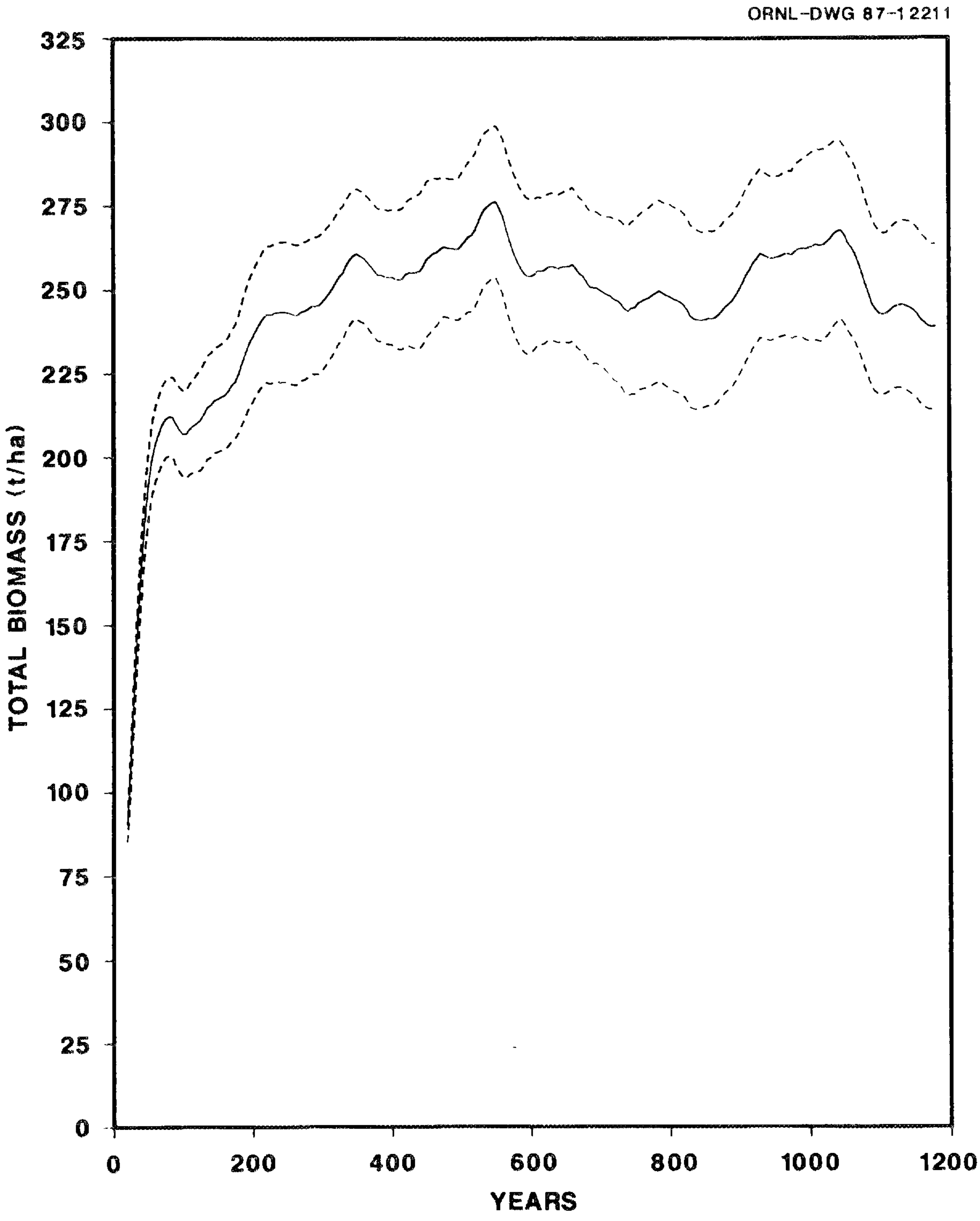

Fig. 9. Simulated total biomass through time of 50 low-elevation plots in the Swiss Midland (see Fig. 4).

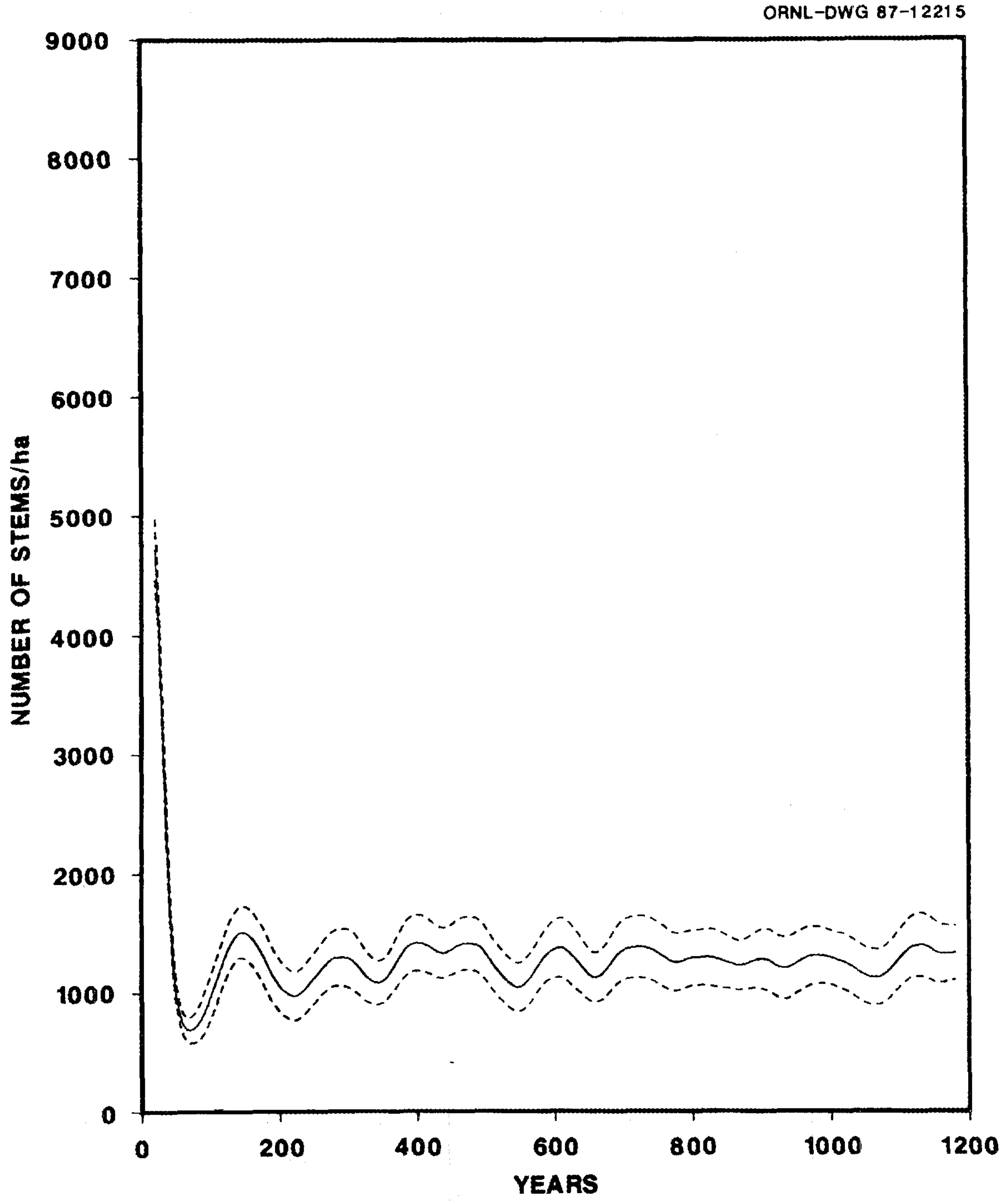

Fig. 10. Simulated number of stems through time of 50 low-elevation plots in the Swiss Midland (see Fig. 4).

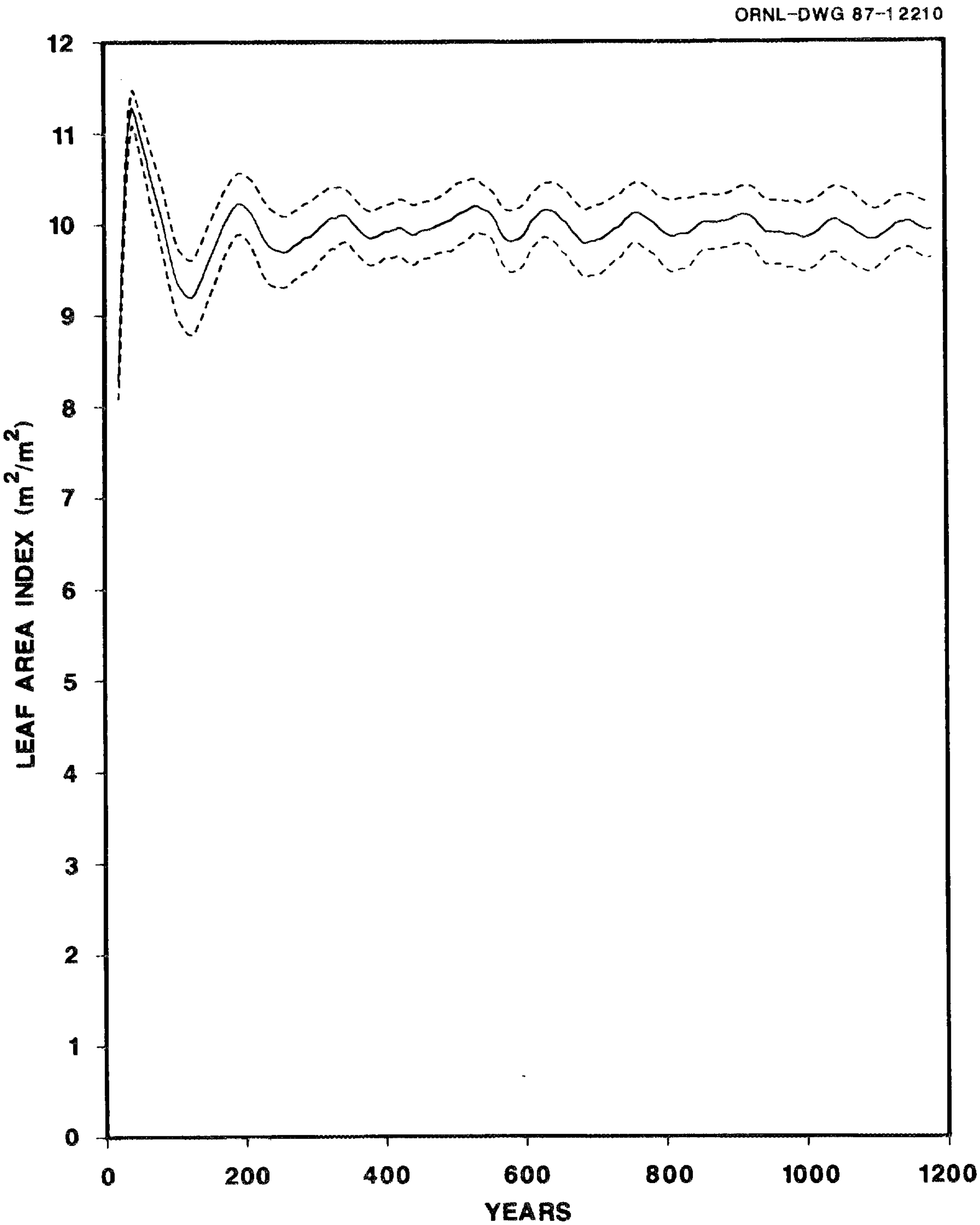

Fig. 11. Simulated leaf area index through time of 50 low-elevation plots in the Swiss Midland (see Fig. 4).

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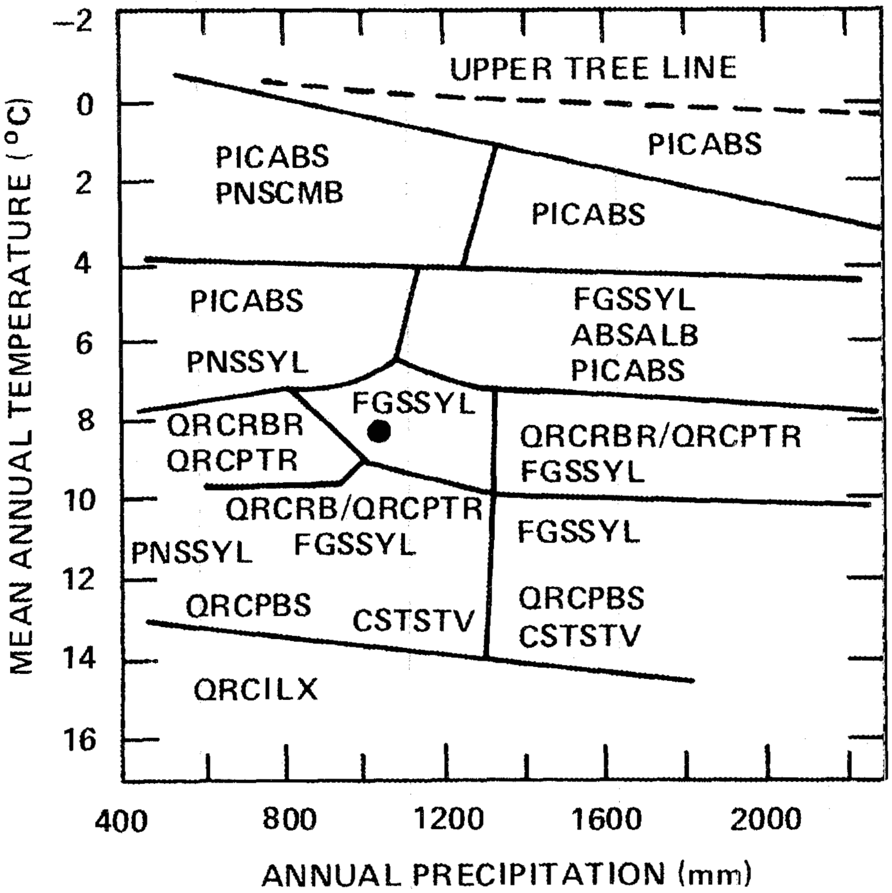

Fig. 12. Dominating tree species of the natural vegetation of Central Europe and the Alps (after Ellenberg 1978). The black dot represents the climatic conditions of the model run represented in this report (meteorological station Bern, Switzerland). Key to the species mnemonics: PICABS (*Picea abies*); ABSALB (*Abies alba*); PNSSYL (*Pinus sylvestris*); PNSCMB (*Pinus cembra*); FGSSYL (*Fagus sylvatica*); QRCRBR (*Quercus robur*); QRCPTR (*Quercus petrea*); QRCPBS (*Quercus pubescens*); QRCILX (*Quercus ilex*); and CSTSTV (*Castanea sativa*).

years, 400 to 800 years and 800 to 1200 years. The first period is characterized by a wave of newly established trees on the bare plot and the short dominance of aspen (*Populus tremula*). The second period exhibits the transition from an early successional forest to an ecosystem dominated by European beech, Norway spruce, and maple. Species diversity is increasing, with Wych elm (*Ulmus scabra*), European ash (*Fraxinus excelsior*), European hornbeam (*Carpinus betulus*), and small-leafed and large-leafed linden (*Tilia cordata* and *Tilia platyphyllos*) gaining importance. All these species increase their biomass at the expense of beech. In phase three the forest composition is relatively stable. However, a model run for a 5000-year period indicated that even though no extrinsic disturbances such as fire or wind are simulated, there is never a Clement'sian climax stage (Clements 1916, 1928, 1936). Runs with extrinsic disturbance factors showed a species composition that is even more unstable and a higher percentage of early successional species. In phase three, European beech is again losing some of its importance, and linden maintains its importance. Silver fir is the species with the biggest change during this phase. The slow-growing, shade-tolerant species has a competitive advantage in later succession; thus, its importance increases at the expense of Norway spruce. It seems that a successional replacement occurs (Huston and Smith 1987). However, in phase four, silver fir reaches its peak and subsequently loses importance. Norway spruce, on the other hand, is able to increase its biomass as the fir canopy starts breaking up in several plots. The model run for a 5000-year period showed that silver fir has its maximum influence around 1200 years, and subsequently loses importance. The simulated alternating dominance of Norway spruce and silver fir described by Mayer (1960) seems to be confirmed in this model approach. Phases two, three, and four of the forest simulation may be interpreted as the averaged successional stages of various associations of the phytosociological unit *Eu-Fagion* (Ellenberg and Klötzli 1972).

Biomass data may be interpreted more accurately if dbh and height distributions were available. The dbh distribution through time is provided on tape 12 (see subroutine OUTPUT). The height distribution may be derived from the dbh distribution by using Eq. (12). The height distribution permits the determination of dominant, codominant, and understory trees in the canopy. The forest simulation presented here shows a dominance of aspen, European beech, Norway spruce, and maple in the upper part of the canopy during phase one. After the canopy is fully developed (highest trees > 25 m, phase 2), European beech and Norway spruce dominate the upper canopy. They are also important species in the height class 10 to 25 m, together with maple, elm, and silver fir. In phase three, silver fir, Norway spruce, and European beech dominate the upper canopy. In phase four, however, silver fir outgrows Norway spruce on many plots and diminishes the importance of European beech in the upper canopy. Despite the important role of silver fir, beech is able to maintain its role as a codominant species in the height class 10 to 25 m. In this height class, it is confounded with silver fir, maple, European hornbeam, linden, and European ash. As the fir canopy starts breaking up towards the end of phase four, Norway spruce and European beech increase their importance in the upper canopy. The understory trees reflect more or less the shade tolerance of the different species. Consequently, elm, maple, beech, European hornbeam, linden, and silver fir dominate this height class in late successional stages, whereas aspen and Norway spruce are typical in early successional stages of the plots.

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APPENDIX A

[Note: Microfiche includes the INPUT file for the simulation of 50 low-elevation plots in the Swiss Midland (meteorological station Bern; moderate soil moisture status) (See inside back cover.)]

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