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VALLA (Version 1.0): A Simulation Model for Growth of American Wildcelery

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP) and the Upper Mississippi River – Illinois Waterway (UMR-IWW) System Navigation Study. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, under the purview of the Environmental Laboratory (EL). The UMR-IWW System Navigation Study is being conducted by the U.S. Army Engineer Districts, Rock Island, St. Louis, and St. Paul, under the authority of Section 216 of the Flood Control Act of 1970. Funding for the APCRP was provided under Department of Army Appropriation Number 96X3122, Construction General. The APCRP is managed under the Center for Aquatic Plant Research and Technology (CAPRT), Dr. John W. Barko, Director. Mr. Robert C. Gunkel, Jr., was Assistant Director, CAPRT. Technical monitor during this study was Mr. Timothy R. Toplisek, HQUSACE.

The work described herein was performed by Dr. Elly P. H. Best, Fate and Effects Branch, with programming assistance from Mr. William A. Boyd, Ecosystem Processes and Effects Branch (EPEB). Ms. Anne B. Stewart, AScI Corporation, assisted with the graphics. Dr. Best and Mr. Boyd prepared this report. The report was reviewed internally by Drs. John D. Madsen and Robert Kennedy, EPEB.

This investigation was performed under the direct supervision of Dr. Bobby L. Folsom, Jr., Chief, Fate and Effects Branch, and the general supervision of Dr. Richard E. Price, Chief, Environmental Processes and Effects Division, and Dr. John W. Keeley, Acting Director, EL.

At the time of publication of this report, Director of ERDC was Dr. James R. Houston. Commander was COL James S. Weller, EN.

This report should be cited as follows:

1   Introduction

A simulation model for biomass dynamics of a submersed American wildcelery vegetation has been developed and called VALLA. The model is based on carbon flow through the vegetation within a meter squared (m^2) water column. It includes descriptions of several factors that affect biomass dynamics, such as site-characteristic changes in climate, water temperature, water transparency, water level, pH and oxygen effects on CO_2 assimilation rate at light saturation, wintering strategies, grazing and mechanical control (removal of shoot biomass), and latitude. The characteristics of the community and of site can be easily modified by the user. VALLA is based on modeling concepts and approaches similar to those used to model two other submersed macrophytes, hydrilla (HYDRIL; Best and Boyd 1996; Boyd and Best 1996) and Eurasian watermilfoil (MILFO; Best and Boyd 1999a,b).

VALLA incorporates insight into the processes affecting dynamics of an American wildcelery community in relatively shallow, hard water (0.2- to 6-m depth; dissolved inorganic carbon concentration>0.8 mmol and pH ranging from 7.6 to 9.4). It has been calibrated on data pertaining to an American wildcelery community in Chenango Lake, New York. At this site, growth starts from the subterranean tubers alone without wintering shoot biomass present. Shoot biomass usually peaks once a year, in July, and intensive downward transport of soluble carbohydrates occurs after flowering has been initiated. This is used for the formation of tubers that grow into the sediment.

VALLA simulated the dynamics of plant and tuber biomass in Chenango Lake well over a period of 1 to 5 years. The model has also been used to calculate plant and tuber biomass for other sites with good results, notably Lake Mendota in Wisconsin, with a temperate climate, and Fort Lauderdale, Florida, with a tropical climate.

Sensitivity analysis showed that maximum plant biomass of an American wildcelery community is most sensitive to a change in photosynthetic activity at light saturation and far less sensitive to a change in light use efficiency. Maximum plant biomass was also strongly affected by changes in plant density but less than by changes in photosynthetic activity at light saturation. In general, the same parameter changes that influence maximum plant biomass were important determinants of end-of-year tuber numbers.

Environmental factor analysis indicated that maximum plant biomass was very sensitive to changes in water transparency and water depth, far more than

tuber number. A change in climate affected end-of-year tuber biomass more strongly than simulated maximum plant biomass.

VALLA can be used as a tool to predict the dynamics of an American wildcelery community over 1- to 5-year periods. Running the model with different parameter values specific for any particular site and/or treatment, e.g., biomass removal to a certain water depth, helps in gaining insight into the predominant mechanisms regulating submersed plant dynamics.

A detailed description of the model is given by Best and Boyd (in preparation).

2   Installation and Execution of the Model

System Requirements

There are few requirements for running VALLA (Version 1.0). The minimum RAM memory requirement should be at least 512 kb. A mathematical coprocessor is in general not required but will often speed up the calculations considerably. A free hard disk space of about 1 Mb is required.

Installing VALLA (Version 1.0)

The initial step to install VALLA is to create a new directory, with the name "WILDCEL," using the DOS command MKDIR. For example, the DOS command "MKDIR C:\WILDCEL" creates a new directory on the C drive called WILDCEL. Copy the contents of the floppy diskette to the directory C:\WILDCEL by using the following command:

XCOPY A:\WILDCEL*.* C:\WILDCEL \ *.* /s

This diskette contains the VALLA.EXE file, all necessary input data files, as well as a file used to display the model output graphically (TTSELECT.EXE). Input files included with this diskette are as follows:

> *a.* MODEL.DAT
>
> *b.* TIMER.DAT
>
> *c.* CONTROL.DAT
>
> *d.* RERUNS.DAT

Available weather data files are included in the subdirectory /WEATHER. The user can select any one of these weather files as input for the VALLA model or may choose to create a weather file specific to a particular site. Output parameters are listed in Appendix A. The content of the weather data files is discussed in Chapter 3 of this manual, and an example of a typical weather data file can be seen in Appendix B.

Executing VALLA (Version 1.0)

   The VALLA model does not require interactive input during execution. The runs have been specified completely in the data files. To execute the model, simply type

   VALLA <CR> (carriage return).

An introductory screen appears and the user is prompted to press <ENTER>. During execution, the model will display the run number, year number, and day number on the screen each time output to file is executed. During execution, errors and warnings may occur from the weather system and/or from the other modules of the model. These errors/ warnings generally consist of one line of text. If the simulation is terminated by an error during the dynamic section of the run, the outputs generated before the error in that particular run occurred are written to a temporary file but are not written to the output file until the terminal section of the model is reached.

3   Program Structure and Data Files

Program Structure

The source code for VALLA (Version 1.0) is written in Fortran77. The model runs within a system called the FORTRAN Simulation Environment (Version 2.1), hereafter referred to as FSE. The FSE allows a simulation model to be written with emphasis on the modeling itself rather than on other things such as time, file i/o, etc. More information is available on running the model within the FSE in Chapter 5 herein.

Subroutines called during the execution of the VALLA model include MODELS, MODEL, ASTRO, TOTASS, and ASSIM. A brief description of each subroutine follows:

    a. MODELS - This subroutine is the interface routine between the FSE-driver and the simulation model. The FSE-driver calls this routine and transfers relevant 'environment' variables (such as TIME, OUTPUT, etc.) to this routine.

    b. MODEL - This subroutine is called from subroutine MODELS. It is the routine where specific calculations for wildcelery growth begin.

    c. ASTRO - This subroutine is called from the MODEL routine each day of the simulation period. It calculates astronomic day length, photoperiodic day length, and diurnal radiation characteristics.

    d. TOTASS - This subroutine is called in the MODEL subroutine. It calculates daily total gross assimilation by performing a Gaussian integration over time. At three different times of the day, radiation is computed and used to determine assimilation.

    e. ASSIM - This subroutine is called from subroutine TOTASS. Plant biomass is distributed within the layers of the plant, and the instantaneous carbon dioxide assimilation rate of the plant is computed in this subroutine.

A diagram illustrating the program structure of the model is shown in Figure 1.

```
                    MAIN

        * Displays model header

        * Calls FSE

        * END
```

```
                    FSE
                   driver

         (Fortran Simulation
          Environment)

              version 2.1
```

```
               subroutine
                 MODELS

         * Interface FSE-driver
                   and
             simulation model
```

```
               subroutine
                 MODEL
        Declaration of:
        - Formal parameters
           (shell terms)
        - Model parameters etc.
        - Calculations
        - Calls to subroutines
```

```
          subroutine
            ASTRO

        * Photoperiod

        * Daylength

        * Irradiation
```

```
          subroutine
            TOTASS

        * Daily total gross
            assimilation
          (3-point Gaussian
            integration)
```

```
          subroutine
            ASSIM

        * Light attenuation
          water + vegetation

        * Instantaneous
          gross assimilation
          (0.1 m depth layers)
```

Figure 1.   Relational diagram illustrating the organization of the model VALLA and its subroutines in
                combination with the FSE shell

Data Files

Most of the parameters and initial values of the various processes are read from data files. This has the advantage in that the model does not have to be recompiled and linked each time changes are implemented to the input data. There are four input files required to run the VALLA model (excluding the weather data file) with a potential for other input files available. The model also typically creates three output data files. The input and output files associated with VALLA are discussed in this section.

Input files

The MODEL.DAT file: This data file contains initial constants, model parameters, as well as data used for functions. An example of the MODEL.DAT file is shown in Appendix B.

The TIMER.DAT file: This data file specifies variables for the following:

a. Time control

    (1) Start time and finish time.

    (2) Time-step integration.

    (3) Year.

b. Output

    (1) Time between different outputs.

    (2) Format of the output file.

    (3) Selection of output variables.

c. Weather control

    (1) Directory in which the weather data are stored.

    (2) Country code.

    (3) Station number.

An example of the TIMER.DAT file is shown in Appendix B.

The RERUNS.DAT file: If the reruns file is absent or empty, the model will execute a single run (1 year) from the standard data files. By creating a reruns file, the model will execute additional runs with different parameters and/or initial values for the state variables (or even different input files). Therefore, the total number of runs made by the model is always one more than the number of rerun sets (Appendix B). The format of the rerun files is identical to that of the

other data files, except that the names of variables may appear in the file more than once.

The CONTROL.DAT file: This file contains the names of both input and output files used during the execution of VALLA. An example of the CONTROL.DAT file is shown in Appendix B.

Output files

VALLA creates three standard output files with a potential fourth, binary file: RES.DAT (Appendix B), MODEL.LOG, WEATHER.LOG, and RES.BIN.

The RES.DAT file: This file contains the output of the model with the reruns (if present) merged below each other in the file. The file can be inspected using an on-screen text editor. The format of the output file RES.DAT depends on the value of the variable IPFORM from the timer file (Appendix B).

The MODEL.LOG file: This file may contain the messages from routines used during the simulation. Messages about replacements by the reruns facility can be particularly useful. To make sure the execution of the model is without errors, this file should be inspected.

The WEATHER.LOG file: This file contains all the messages generated by the weather system. By default, all the comment headers of the data files, all warnings, and all errors from the weather system are written to this log file. If errors or warnings occur during a run, a message is displayed shortly before the termination of the model about possible errors or warnings. These messages are explained in more detail in the log file.

The RES.BIN file: The variable "DELTMP" found in the TIMER.DAT file (Appendix B) determines if the temporary output data (RES.BIN) should be deleted or saved at termination of the simulation (DELTMP = 'N', Do not Delete, DELTMP = 'Y', Delete). Using this file, it is possible to generate graphs of the model's output on IBM-PC's and compatibles after termination of the simulation. This can be done using the TTSELECT program, provided DELTMP is set to 'N' in the timer file. An executable of this program is included in this distribution package. For more details on TTSELECT, see Displaying Output.

Weather data files

The weather data system basically consists of two parts: weather data files and a program to retrieve data from those files (Van Kraalingen et al. 1991). A single data file can contain, at most, the daily weather data of one meteorological station for one particular year. The country name (abbreviated), station number, and year to which the data refer are reflected in the name of the data file (e.g., USA6.978 applies to data from the American (USA) meteorological station in Binghamton (6) for the year 1978).

Daily values are provided for the following weather parameters:

Name	Unit
Global radiation(daily total)	kJ/m^2/d
Minimum air temperature	degrees Celsius
Maximum air temperature	degrees Celsius
Vapor pressure	kPa
Wind speed (daily average)	m/s
Rain (daily total)	mm/d

The user can create a weather data file that is unique to a particular site. The file consists of four parts: a file header containing some explanatory text, one line with location parameters of the station, lines with measured data and, optionally, so-called status lines giving information on the way missing data should be handled by the reading program (Van Kraalingen et al. 1991; Van Kraalingen 1995). An example of a weather file can be seen in Appendix B.

Displaying Output

The program TTSELECT.EXE is included within this distribution package. Execution of this program allows the user to graphically view output parameters stored in the file RES.BIN. To use this feature of the package, after termination of the VALLA simulation, type the following command:

TTSELECT <CR> (carriage return).

A list of all possible output parameters will then be displayed at the top of the computer screen. The user must select two or more of these parameters by entering the parameter name separated by a comma (NOTE: Parameter names must be entered exactly as they appear on the screen). The first parameter entered (always TIME) will appear as the x-axis variable while all other variables entered will be plotted along the y-axis. Once all output parameter names are entered, the user must follow instructions on the screen by pressing a <CR> (carriage return). The output graph will then be displayed.

There are several options available once the graph is displayed: (a) the plot can be saved as a file, (b) it can be saved as a screen dump file for later printing, or (c) it can be printed on a Hewlett Packard DeskJet or LaserJet printer. If desired, another set of parameters can be viewed by entering different output parameters. At anytime, the user may exit the TTSELECT.EXE program by typing CONTROL Z followed by a <CR> (carriage return).

4   Program Output

Example Runs

Example simulations using VALLA (version 1.0) were made to provide further information, facilitate proper execution, and to demonstrate applications. The following summary includes five examples, in which the contents of various input files are modified.

The user can produce simulation results for a specific scenario by modifying parameters in the MODEL.DAT file. VALLA can rapidly provide information on the growth and development rate of wildcelery over a specified period.

Example 1: Nominal run

The current MODEL.DAT file (see Appendix B) contains data required to execute a nominal run. In the section "Initial constants" in the MODEL.DAT file, all initial plant biomass values, except that of the initial dry weight of individual tubers (INTUB), are set to zero. These values pertain to the initial dry matter (live and dead) of leaves, roots, stems, and storage components and indicate that at the beginning of the simulation there is no plant material, live or dead, in the system. In this situation, growth starts from the tubers in the tuber bank. INTUB is set at 0.09 g DW (Korschgen and Green 1988; Korschgen, Green, and Kenow 1997). Other characteristics of the tuber bank used for this run are listed in the section "Model parameters." These parameters are: tuber bank density (NDTUB) set at 233 tubers m^{-2} (Titus and Stephens 1983), and standard plant density (NPL) set at 30 plants m^{-2}.

In the MODEL.DAT file under the section "Initial constants," only the initial dry weight (DW) of individual tubers has a value>0, i.e., a value of 0.09 g DW. All weights of other plant parts are initialized at 0. This run describes the typical behavior of a wildcelery vegetation in temperate regions, one that hibernates with subterranean tubers alone without any other remaining plant parts. The run begins with a total live plant biomass of 0 g DW m^{-2} on day 1 of the simulation. The simulation is executed for 1 full year using weather data contained in the file 'USA6.978'. This file contains weather data obtained from the weather station at Binghamton airport (minimum and maximum air temperature and vapor pressure) and a weather station located at Cornell University (irradiance and wind speed), both in Ithaca, NY, and in 1978; the file is located on the subdirectory C:\WILDCEL\WEATHER.

For this nominal run, the model can be executed without changing input files used by the model. To ensure that the current directory is WILDCEL, from the C drive, type the command:

CD/WILDCEL <CR>

and then type

VALLA <CR>

to execute the simulation model.

After the introductory screen is displayed and execution begins, the model will display the run number, year number, and day number on the terminal screen each time output to file is done. Upon completion, VALLA lists the names and contents of output files created.

Example 2: Initial biomass >0.0 g

In Example 2, an almost identical MODEL.DAT file is used as for the nominal run. Only the initial plant biomass values under the section "Initial constants" have been changed. This run begins with 20-g DW live plant biomass (excluding tubers) per m^{-2}, and the same tuber bank as for the nominal run, on day 1 of the simulation. A situation like this may occur in warmer, subtropical-tropical regions (Haller 1974; Godfrey and Wooten 1997). Plant biomass is partitioned over the leaves, stems, and roots as follows. Of the total plant live weight, 71.8 percent is in the leaves, 15.9 percent in the stems, and 12.3 percent in the roots (Haller 1974; Titus and Stephens 1983). The weights are calculated below:

$$IWLVG = 0.718 \times 20 = 14.36 \qquad \text{! Initial dry matter of live leaves}$$
$$\text{! (g DW.m}^{-2})$$
$$IWRTG = 0.123 \times 20 = 2.46 \qquad \text{! Initial dry matter of live roots}$$
$$\text{! (g DW.m}^{-2})$$
$$IWSTG = 0.159 \times 20 = 3.18 \qquad \text{! Initial dry matter of live stems}$$
$$\text{! (g DW.m}^{-2})$$

The calculation given above has to be done each time a run with a different initial biomass is desired. The calculated initial values for plant organ weights must be changed in the MODEL.DAT file, the MODEL.DAT file should be saved, and VALLA should be executed as described for the nominal run. Before changing the nominal MODEL.DAT file for the current example, this file has to be saved under a different name, e.g., MODELVC.DAT. Each VALLA run uses only 'the' MODEL.DAT file as input (so, make sure you only have one MODEL.DAT file in the WILDCEL directory).

Example 3: Changes in the tuber bank: Density, individual tuber weight, and tuber number concurrently initiated

In Example 3, an almost identical MODEL.DAT file is used as for the nominal run. Only the tuber bank density value under the section "Model parameters" has been changed. This run begins with 0 g DW live plant biomass (excluding tubers) per m^{-2}, and a smaller tuber bank (of 100 tubers m^{-2}) than in the nominal run on day 1 of the simulation. A situation like this may occur in water bodies where tubers have been grazed by canvasbacks (Lovvorn and Gillingham 1996). Results of this simulation are discussed in the section, Example Output, Chapter 4.

Individual tuber weight and tuber number concurrently initiated by each plant depend on the light level at which the plant grows. Both tuber weight and number decrease with light level according to the relationship shown in Figure 2 (Donnermeyer and Smart 1985). The tuber weight used in the nominal run is representative for the light level in the calibration situation. However, light levels experienced by wildcelery vegetation at other sites can be higher or lower, and consequently tuber behavior must be modified to apply to those situations. For instance, in a case where it is known that a tuber size of 0.06 g DW.tuber^{-1} is representative, the following changes must be made in the MODEL.DAT file:

In the "Initial constants" section of the MODEL.DAT file:

INTUB = 0.06   ! Initial dry weight of a tuber
                    ! (g DW.m^{-2})

In the "Model parameters" section:

NINTUB = 3.8   ! Tuber number concurrently initiated per plant
                    ! (g DW.m^{-2}); read from Figure 2

SURPER = 15.3   ! Survival period of tubers (d); calculated as
                    ! (0.06(new INTUB value)/0.09(nominal INTUB value))
                    ! × 23 (nominal SURPER value)

TWCTUB = 6.84   ! Total critical dry weight of new tubers
                    ! (g DW.m^{-2}); calculated as
                    ! 0.06 (INTUB) × 3.8 (NINTUB) x 30 (NPL)

When starting the simulation with a tuber bank density<30 tubers m^{-2}, e.g., 18, 30 should be replaced by 18 in the last calculation.
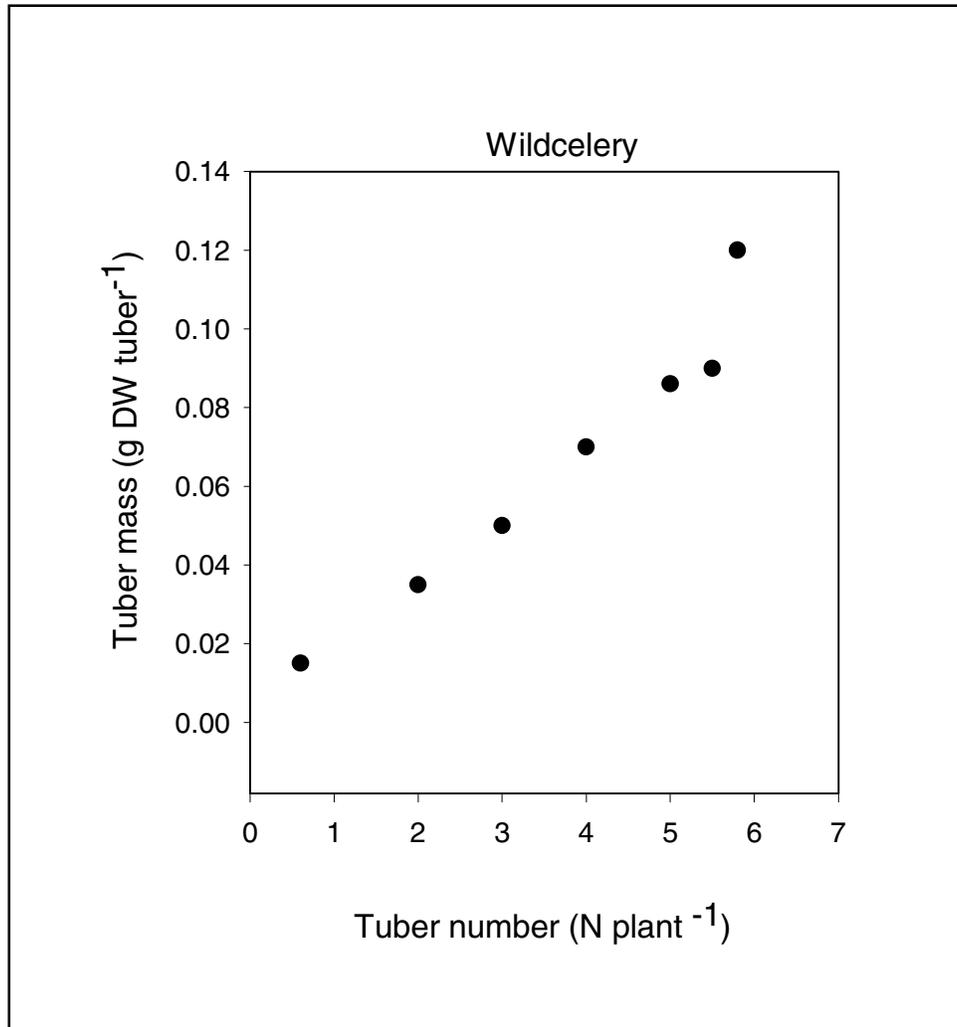
Figure 2. The relationship between tuber number concurrently initiated per plant
and tuber size for wildcelery (Donnermeyer and Smart 1985)

Example 4: Wildcelery populations at different water depths

   In Example 4, a MODEL.DAT file is used, almost identical to the
MODEL.DAT file for the nominal run; only the values for the water depth
function (DPTT) under the section "AFGEN functions" have been changed for
three separate runs, respectively, i.e., 0.5-, 2.5-, and 5-m depths (nominal depth
is 1.4 m).

   Changing this parameter set enables running the model for a wildcelery stand
in two different situations:

   a. In a water body with annually changing water depth, by replacing the
        two identical nominal values by two other identical values pertaining to
        that water body; and/or

b. In a water body with seasonally and annually changing water depth, by replacing the one nominal value by daily water level values pertaining to that water body (important for reservoirs and flood-prone, riverine, environments).

Data pairs must be entered, by giving first the Julian day number followed by "." and subsequently, the value of the water depth at that day followed by ",". The results of the latter runs are not presented here.

Example 5: Wildcelery populations in water bodies with different transparencies

In Example 5, a MODEL.DAT file is used. It is almost identical to the MODEL.DAT file for the nominal run; only the values for the water transparency function (LT) under the section "AFGEN functions" must be changed. Data pairs must be entered, by giving first the Julian day number followed by "." and subsequently, the value of the extinction coefficient at that day followed by ",". The results of this run are not presented here.

Changing this parameter set enables running the model for the same wildcelery stand in a water for different years with annually and/or seasonally changing light extinction coefficients, and/or for different wildcelery stands in lakes differing in water transparency. Water transparency values, expressed in Secchi depth (in meters), should be converted to light extinction coefficients (in 1/meter) as follows: light extinction coefficient = 1.65/Secchi depth. This conversion factor has been reliable in a Secchi depth range from 0.5 to 2 m (U.S. Environmental Protection Agency (USEPA) 1992).

Example Output

The output of Examples 1 and 2 is presented in the Figures 3 and 4. These results demonstrate the impact beginning plant biomass can have on the simulated plant, tuber biomass, and tuber numbers of wildcelery.

All output parameters listed in Appendix A can be displayed by selecting the desired abbreviation using TTSELECT, since all data are contained in the RES.BIN file. However, if the numbers on the total live plant biomass, e.g., are desired as output, the abbreviation of this variable (TGW) should be freed (remove star in front of this variable) in the TIMER.DAT file, and the user can find the desired data in the RES.DAT file. For the accumulated live+dead biomass, the variable would be TW; for the live weights of the plant organs, the variables would be TWLG, TWST, TWRG, and for their dead weights TWLD, TWSD, TWRD.

Results of the nominal run (Figure 3) indicate that the total simulated plant biomass started with 0 g at day 1 of the simulation and showed live plant biomass from day 106 onwards. Plant biomass peaked on day 252 at 56.2 g DW.m^{-2}. The simulated tuber weight decreased from 20 g DW m^{-2} on day 1
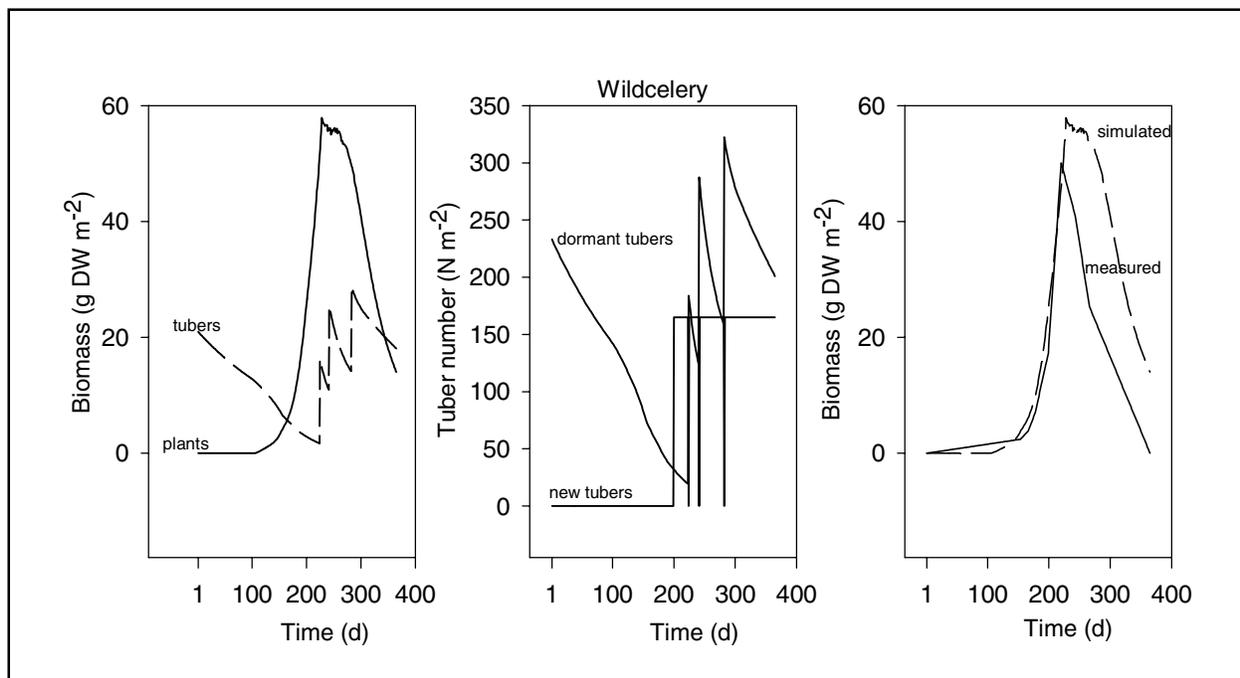
Figure 3. Simulated biomass of plants, dormant and new tuber numbers, and measured plant biomass of a wildcelery community in Chenango Lake, New York. Nominal run. Field data from Titus and Stephens (1983); climatological data 1987, Binghamton, New York (longitude 75° 50' E, latitude 42° 15' N); water depth 1.4 m; light extinction coefficient 0.43 m^{-1}

Figure 4. Simulated biomass of plants and tubers of a wildcelery community in Chenango Lake, New York, started from (a) nominal initial data; (b) nominal initial data and 20 g plant biomass; and (c) nominal initial data and a tuber bank density of 100 m^{-2}

onwards to 0, until new tubers were formed (from day 224 onward). Once finished, each tuber class is added to the tuber bank, which loses weight by senescence. Two tuber classes were complete, and the third one was almost finished. Tuber classes and numbers can be followed also. Simulated and measured plant biomass curves coincided in timing, and the measured peak biomass exceeded the simulated biomass slightly.

Total plant biomass of wildcelery was usually higher for the run with initial plant biomass present than for the nominal run (Figures 4a, b). Live plant biomass peaked at day 228 with 347.6 g DW m^{-2} in the run with initial plant biomass, and with 56.2 g DW m^{-2} in the nominal run. Four tuber classes were finished and a fifth class initiated in the population with initial plant biomass present. Initial biomass influenced not only the total live and total (live+dead) dry weight to a great extent, it also influenced the tuber bank weight.

Total plant and tuber biomass were identical in the runs initiated with low and with nominal tuber bank density (Figures 4c, a). This phenomenon is explained by the fact that the model vegetation has a typical plant density of 30 plants m^{-2}. Thus, a tuber bank density of 100 m^{-2} at day 1 can generate 30 full-grown plants under the chosen environmental (weather, water depth, and tranparency) conditions. At tuber bank densities <30 tubers m^{-2} at day 1, e.g., 15, that initial tuber number (of 15) is used in the model.

The output of Example Run 5 is presented in Figure 5. Simulated live plant biomass generally increased with increasing rooting depth, but tuber production was similar at the shallow (0.5 m) and deep rooting depths (2.5 m) and higher at the nominal rooting depth of 1.4 m.

We hope that these example runs and their output provided in this section will help users conceptualize simulation runs that will generate useful information to address specific questions.

Use of Different Weather Files

Climate is an important factor influencing wildcelery biomass. Phenology is tied indirectly to air and/or water temperature through development rate. Weather data are available for different climatological conditions ranging from temperate to tropical. To illustrate the impact that climate can have on plant and tuber biomass of wildcelery, VALLA was executed using a weather file representing both a temperate and a tropical climate. In both cases, the same nominal MODEL.DAT file was used for biomass-specific input data. Under tropical conditions in the field, however, wintering plant biomass is usually present and the vegetation tends to have a lower plant species specific light extinction coefficient (K tropical 0.0051-0.019 m^2.g DW^{-1} (Ikusima 1970; Blanch, Ganf, and Walker 1998) versus K temperate 0.0235 m^2.g DW^{-1} (Titus and Adams 1979; Best and Boyd in preparation, section entitled "Simulated and measured behavior of a wildcelery community at other latitudes"). The TIMER.DAT file specified for the nominal run is the temperate weather file
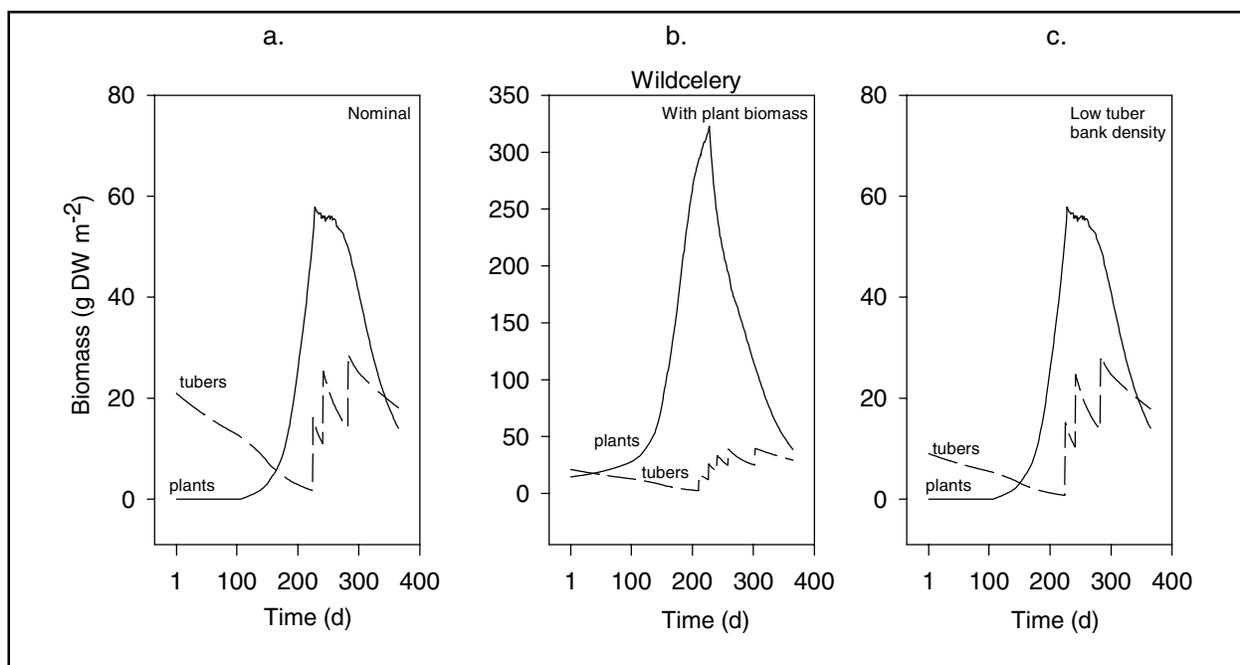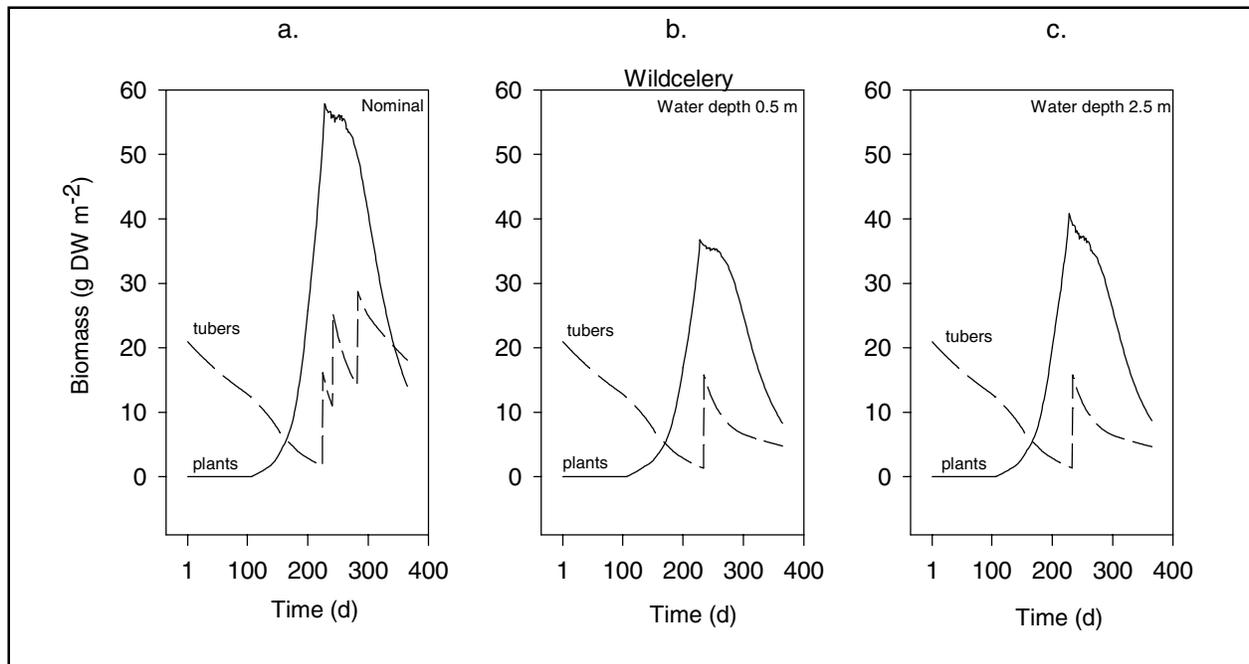
Figure 5. Simulated biomass of plants and tubers of a wildcelery community in Chenango Lake, New York, started from nominal initial data, and (a) 1.4-m water depth; (b) 0.5-m water depth; (c) 2.5-m water depth

(USA6.978) and for the tropical run is the tropical file (IND1.978). Each weather file is described below:

Temperate Weather File
Country: United States of America
Station: Binghamton
Year: 1978
Longitude: 75° 50' W
Latitude: 42° 15' N
Elevation: unknown m

Tropical Weather File
Country: India
Station: Patancheru
Year: 1978
Longitude: 78° 28' E
Latitude: 17° 27' N
Elevation: 21 m

Output of both simulations is shown in Figure 6, where simulated live plant and tuber biomass in a temperate and tropical climate over a 1-year period are illustrated. Apparently, wildcelery communities in a tropical climate exhibit a lower peak plant biomass than in a temperate climate, when growth would start from tubers alone without wintering plant biomass present and using a K-value
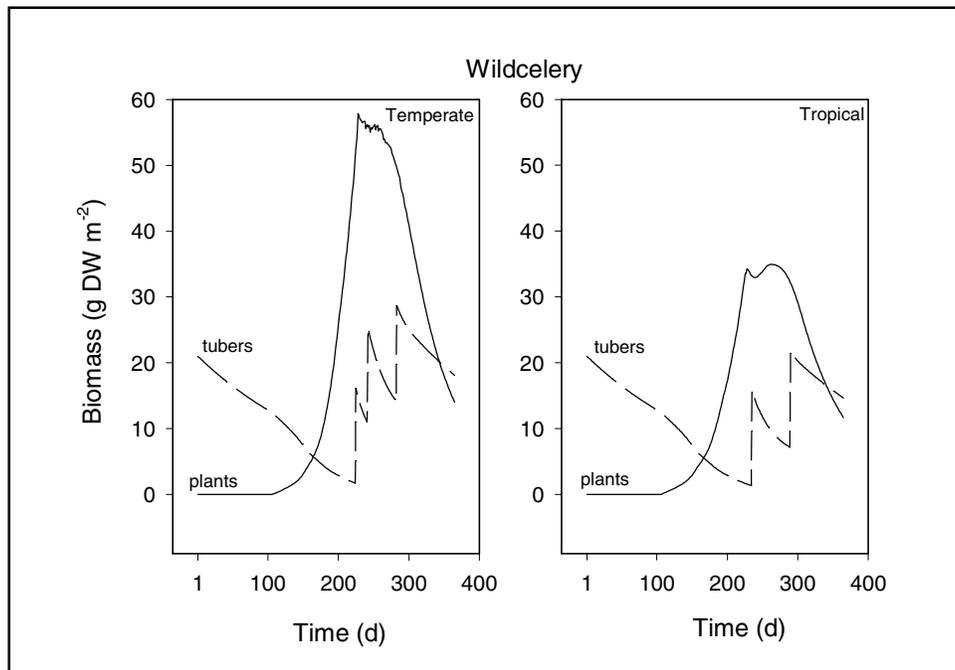
Figure 6. Simulated biomass of plants and tubers of a wildcelery community at different latitudes, started from nominal data. (a) Chenango Lake, New York, (longitude 75° 50' E, latitude 42° 15' N); climatological data 1987. (b) Patancheru, India (longitude 78° 28' E, latitude 17° 27' N); climatological data 1978

typical for temperate regions. Tuber biomass tends to accumulate toward the end of the growing season in both climates.

Removing Plant Biomass By Mechanical Harvesting

VALLA can also be used to calculate effects of various control methods on biomass and survival of a wildcelery stand, e.g., of mechanical harvesting at various times and water depths. The model can be run for this purpose by making changes in the section "Model parameters" of the MODEL.DAT file, by indicating: (a) that harvesting occurs (HAR = 1), (b) the day at which harvesting occurs (HARDAY = desired day number, e.g., 15 July or day 196), and (c) the harvesting depth below the water surface (HARDEP = desired depth, e.g., 1.0 m). By these changes, all plant biomass contained in those layers affected by the harvesting depth is removed at the specified day in the simulation run. Examples of effects of various harvesting times and depths are presented by Best and Boyd (in preparation) in the section entitled "Simulated behavior of a wildcelery community subject to biomass removal; effects of mechanical harvesting and grazing."

Multiple-Year Runs

VALLA has the ability to generate multiple-year simulation runs. This is a critical feature when examining plant growth for consecutive years, and/or in the analysis of the effect of a different value for an input parameter. Multiple-year simulation runs can be accomplished using the RERUNS.DAT file which is illustrated in Appendix B of this report. If the RERUNS.DAT file is absent or empty, the model will execute a single run, using the data from the standard data files (i.e. MODEL.DAT and TIMER.DAT). If the RERUNS.DAT file is present and contains different parameters and/or initial values for the state variables, the total number of runs made by the model is always one more than the number of rerun sets. Names of variables originating from different data files can be redefined in the same rerun file. Arrays can also be redefined in a rerun file. The order and number of variables should be the same in each set. A new set starts when the first variable is repeated (Appendix B).

5 Running the Model Within a Shell

This chapter gives a brief description of how the FSE shell drives the VALLA model. All execution starts with a MAIN program (Figure 1). This is a short program that displays the header and calls the FSE-driver. The FSE-driver then performs a number of actions. It reads the input and output file names needed by the model from the file CONTROL.DAT. This file contains the names of the input files TIMER.DAT, RERUNS.DAT, and MODEL.DAT. The CONTROL.DAT file also contains names of the model's output files (RES.DAT and MODEL.LOG). From the weather control variables in the TIMER.DAT file, the weather system determines which weather data file is required.

The FSE-driver then calls a MODELS subroutine and transfers all relevant 'environment' variables (such as TIME, OUTPUT, ... etc.) to this routine. The MODELS subroutine provides the interface between the FSE-driver and the simulation model. This routine in turn calls the MODEL subroutine which begins execution of the various routines within the VALLA source code.

It is not necessary to know the FORTRAN details of what is going on in the FSE-driver. A discussion of information that is passed from the FSE-driver to the model and vice versa can be found Van Kraalingen (1995).

6   Model Features

Features of VALLA are as follows:

a.   Phenology is tied indirectly to air temperature through development rate, and is, therefore, independent of day of year; thus, the model can be used under climatological conditions ranging from temperate to tropical;

b.   Plant growth starts from the subterranean tuber bank alone, even from tuber densities as low as 1, as well as from the tuber bank with wintering plants present;

c.   One or more plant cohorts can be active in temperate as well as tropical climates; in case of plantlet death during prolonged periods of negative net photosynthesis early in the season, the dead plant cohort is succeeded by the next sprouting plant cohort;

d.   Photosynthetic response is to instantaneous irradiance;

e.   Air and/or water temperatures can be used to run the model;

f.   The model can be used for communities at water depths, which can vary between years and daily within the year, with depths ranging from 0.2 to 6.0 m;

g.   Plant parameter values and climatological variables can be easily changed;

h.   Effects of removal of plant biomass, through mechanical harvesting, and of tubers, through grazing, can be calculated, if desired.

7 Application Possibilities

VALLA can be used to assess behavior of a wildcelery vegetation under various site-specific and climatological conditions, and it can be run with user-specified input values for plant and tuber biomass and tuber bank density.

Effects of man-made activities, such as mechanical harvesting at different times and at various water depths and water level and water quality management, can also be calculated using the model. Thus, in the latter case it can be used as a tool for aquatic plant and water management agencies (see, e.g., Bartell et al. in preparation).

The present version of VALLA (1.0) has been developed as a stand-alone simulation model. It can be relatively easily modified to communicate with ecosystem models, because it is written in FORTRAN77 and its structure is simple. It is planned to link VALLA to a Geographical Information System through an appropriate interface like AEGIS+ (Luyten et al. 1994).

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Appendix A
Output Parameters Available

Abbreviation	Explanation	Dimension
DAVTMP	Daily average temperature	^oC
DAYL	Day length	h
DDTMP	Daily average daytime temperature	^oC
DTEFF	Daily effective temperature	^oC
DTGA	Daily total gross CO_2 assimilation of the plant	$g\ CO_2.m^{-2}.d^{-1}$
DPT	Water depth	m
DVS	Development phase of the plant	-
FGROS	Instantaneous CO_2 assimilation rate of the plant	$g\ CO_2.m^{-2}.h^{-1}$
GPHOT	Daily total gross assimilation rate of the community	$g\ CH_2O.m^{-2}.d^{-1}$
IRS	Total irradiance just under the water surface	$J.m^{-2}.s^{-1}$
MAINT	Maintenance respiration rate of the plant	$g\ CH_2O.m^{-2}\cdot d^{-1}$
NDTUB	Dormant tuber number	$dormant\ tubers.m^{-2}$
NGTUB	Sprouting tuber number	$spr.tubers.m^{-2}$
NNTUB	New tuber number $new\ tubers.m^{-2}$	
NTM	Tuber density measured (field site)	$tubers.m^{-2}$
NTUBD	Dead tuber number	$dead\ tubers.m^{-2}$
REMOB	Remobilization rate of carbohydrates	$g\ CH_2O.m^{-2}.d^{-1}$
TEFF	Factor accounting for effect of temperature on maintenance respiration, remobilization, and maximum relative tuber growth rate	-
TGW	Total live plant dry weight (excluding tubers)	$g\ DW.m^{-2}$
TGWM	Total live plant dry weight measured (field site)	$g\ DW.m^{-2}$
TMPSUM	Temperature sum after 1 January	^oC
TRANS	Translocation rate of carbohydrates	$g\ CH_2O.m^{-2}.d^{-1}$
TREMOB	Total remobilization	$g\ CH_2O.m^{-2}$
TW	Total live + dead plant dry weight (excluding tubers)	$g\ DW.m^{-2}$
TWGTUB	Total dry weight of sprouting tubers	$g\ DW.m^{-2}$
TWLVD	Total dry weight of dead leaves	$g\ DW.m^{-2}$
TWLVG	Total dry weight of live leaves	$g\ DW.m^{-2}$
TWNTUB	Total dry weight of new tubers	$g\ DW.m^{-2}$
TWRTD	Total dry weight of dead roots	$g\ DW.m^{-2}$
TWRTG	Total dry weight of live roots	$g\ DW.m^{-2}$
TWSTD	Total dry weight of dead stems 2 or 3 cohorts	$g\ DW.m^{-2}$
TWSTG	Total dry weight of live stems 2 or 3 cohorts	$g\ DW.m^{-2}$
TWTUB	Total dry weight of tubers	$g\ DW.m^{-2}$
TWTUBD	Total dry weight of dead tubers	$g\ DW.m^{-2}$
WTMP	Daily water temperature	^oC

Appendix B
Examples of Data Files

MODEL.DAT File Provided

```
*--------------------------------------------------------------------------------------------*
* MODEL.DAT file                                                                             *
* contains:                                                                                  *
* - Initial constants as far as specified with INCON statements,                             *
* - Model parameters,                                                                        *
* - AFGEN functions,                                                                         *
* - A SCALE array in case of a general translation                                          *
*                                                                                            *
* File name: MODELVC.DAT; input MODEL.DAT file for calibration run of VALLA                  *
* Calibration data cf. Titus & Stephens, 1983; weather file USA6.978 pertaining             *
*   to Binghamton, NY, 1978.                                                                 *
* Date: 10 August 99                                                                         *
*Time: 14:00:00                                                                              *
*--------------------------------------------------------------------------------------------*
* Initial constants
* ---------------------
```

INTUB	= 0.09	! Initial dry weight of a tuber (g DW. tuber^{-1})
IREMOB	= 0.	! Initial value remobilization (g $CH_2O.m^{-2}$)
IWLVD	= 0.	! Initial dry matter of dead leaves (g DW. m^{-2})
IWLVG	= 0.	! Initial dry weight of live leaves (g DW. m^{-2})
IWRTD	= 0.	! Initial dry weight of dead roots (g DW. m^{-2})
IWRTG	= 0.	! Initial dry weight of live roots (g DW. m^{-2})
IWSTD	= 0.	! Initial dry weight of dead stems (g DW. m^{-2})
IWSTG	= 0.	! Initial dry weight of live stems (g DW. m^{-2})
NUL	= 0.	! Zero (0)
REMOB	= 0.0	! Remobilization rate of carbohydrates (g $CH_2O.m^{-2}$)

```
* Model parameters
* -------------------------
```

YRNUM	= 1.	! Year number simulation (1-5) (y)
AMX	= 0.0165	! Potential CO_2 assimilation rate at light ! saturation for shoot tips (g CO_2. g DW^{-1}.h^{-1})
CRIFAC	= 0.0091	! Critical weight per 0.1 m vegetation layer ! (g DW per 0.1 m plnt ht^{-1}. m^{-2})
CVT	= 1.05	! Conversion factor of translocated dry matter into CH_2O (-)
DAYEM	= 1.	! First Julian day number (d)
DELAY	= 1.	! Lag period chosen to relate water temperature to air ! temperature, in cases where water temp. has not been ! measured (d)
EE	= 0.000011	! Initial light use efficiency for shoots (g CO_2. J^{-1})
HAR	= 0.	! Harvesting (0 = no harvesting, 1 = harvesting)
HARDAY	= 304.	! Harvesting day number (d)
HARDEP	= 0.8	! Harvesting depth (measured from water surface; m)
NDTUB	= 233.	! Dormant tuber number (dormant tubers.m^{-2})
NINTUB	= 5.5	! Tuber number concurrently initiated per plant ! (conc.in.tubers.plnt^{-1})

```
NPL            = 30.              ! Plant density (plants.m$^{-2}$)
RC             = 0.06             ! Reflection coefficient of irradiance at water surface
                                  ! (relative; -)
RCSHST         = 12.0             ! Relation coefficient tuber weight- stem length (m g DW$^{-1}$)
RDTU           = 0.018            ! Relative death rate of tubers (on number basis; d$^{-1}$)
REDAM          = 1.              ! Reduction factor to relate AMX to pH and oxygen levels of
                                  ! the water (relative; -)
ROC            = 0.0576           ! Relative conversion rate of tuber into plant material
                                  ! (g CH$_2$O g DW$^{-1}$.d$^{-1}$)
RTR            = .247             ! Maximum relative tuber growth rate at 20 $^o$C
                                  ! (g DW.tuber$^{-1}$.d$^{-1}$)
SURPER         = 23.              ! Survival period sprouting tubers (d)
TBASE          = 3.              ! Base temperature for juvenile plant growth ($^o$C)
TL             = 0.1             ! Thickness per depth layer (m)
TWCTUB         = 14.85            ! Total critical dry weight of new tubers (g DW. m$^{-2}$)


* AFGEN functions
* -----------------------

            ! Daytime temperature effect on AMX as function of DVS (-,-)
AMTMPT =
  -30., 0.00001, 0., 0.00001, 5., 0.12, 15., 0.424, 20., 0.568, 25., 0.735, 30., 0.879,
   35., 1.0, 50., 0.00001


            ! Dry matter allocation to each plant layer (relative; - , layer number)
DMPCT  =
  1.0, .184, 2.0, .184, 3.0, .184, 4.0, .114, 5.0, .114


            ! Water depth as function of day number (m, d)
DPTT=
   1., 1.4, 365., 1.4


            ! Leaf dry matter allocation to each layer of the plant as function of DVS (-,-)
FLT    =
  0., 0.82, 3.5, 0.82, 20.0, 0.82


            ! Fraction of total dry matter increase allocated to leaves as function of DVS (-,-)
FLVT   =
  0., 0.718, 3.5, 0.718, 20.0, 0.718


            ! Fraction of total dry matter increase allocated to roots as function of DVS (-,-)
FRTT   =
  0., 0.123, 3.5, 0.123, 20.0, 0.123


            ! Fraction of total dry matter increase allocated to stems as function of DVS (-,-)
FSTT   =
  0., 0.159, 3.5, 0.159, 20.0, 0.159


            ! Plant species specific light extinction coefficient as function of DVS (m$^2$.g DW$^{-1}$, -)
KT     =
  0., 0.0235, 3.5, 0.0235, 20.0, 0.0235


            ! Water type specific light extinction coefficient as function of day number (m$^{-1}$, d)
LT     =
  1., 0.43, 7., 0.43, 28., 0.43, 35., 0.43, 57., 0.43, 63., 0.43, 68., 0.43, 77., 0.43, 84.,
  0.43, 91., 0.43, 99., 0.43, 105., 0.43, 112., 0.43, 121., 0.43, 135., 0.80, 153., 0.49,
  158., 0.60, 166., 0.47, 178., 0.45, 188., 0.47, 199., 0.50, 222., 0.57, 225., 0.59,
  243., 0.50, 250., 0.43, 266., 0.43, 270., 0.43, 274., 0.43, 280., 0.43, 284., 0.43,
  290., 0.43, 294., 0.43, 298., 0.43, 301., 0.43, 305., 0.43, 310., 0.43, 320., 0.43,
  330., 0.43, 365., 0.43


            ! Relative death rate of roots as function of daily average temperature
            ! (g DW. g DW.d$^{-1}$, $^o$C)
RDRT   =
  0., 0.021, 19., 0.021, 30., 0.042, 40., 0.084, 50., 1.


            ! Relative death rate of shoots as function of daily average temperature
            ! ( g DW. g DW.d$^{-1}$, $^o$C)
RDST   =
```

```
    0., 0.021, 19., 0.021, 30., 0.042, 40., 0.084, 50., 1.

          ! Reduction factor for AMX to account for senescence plant parts over vertical axis
          ! of vegetation (relative; -,-)
REDFT =
  0.0, 1.0, 1.0, 1.0, 20.0, 1.0

          ! Factor accounting for effect of temperature on maintenance respiration,
          !  remobilization, and relative tuber growth rate (relative; -, °C)
TEFFT =
  0.0, 0.0001, 10., 0.5, 20., 1., 30., 2., 40., 4., 45., 6., 50., 0.0001

          ! Daily water temperature as function of day number (°C, day)
WTMPT =
  1.,  5.5, 7.,  5.5, 14., 5.5, 28., 5.5, 35., 5.5, 42., 5.5, 49., 5.5, 57., 5.5, 63., 5.5,
  68., 5.5, 77., 5.5, 84., 5.5, 91., 5.5,  95., 5.5, 135., 13., 153., 23., 156., 21., 158.,
  16., 162., 19., 166., 18., 174., 21., 178., 22., 188., 21., 194., 20., 199., 21., 210.,
  22., 220., 22., 227., 25., 243., 20., 250., 20., 258., 16., 266., 15., 305., 5.5, 310.,
  5.5, 315., 5.5, 320., 5.5, 325., 5.5, 330., 5.5, 335., 5.5, 365., 5.5

          ! Tuber density measured (field site) as function of day number (tubers.m$^{-2}$, d)
NTMT  =
  1., 233., 98., 233., 134., 233., 162., 233., 190., 233., 233., 233., 260., 233., 289.,
  233.,  365., 233.

          ! Total live dry weight measured (field site) as function of day number (g DW.m$^{-2}$, d)
TGWMT =
  1., 0., 153., 2.4, 166., 3.8, 178., 7.1, 199., 17.3, 220., 50.1, 243., 41.0, 266., 25.3,
  365., 0.
```

TIMER.DAT File Provided

```
*---------------------------------------------------------------------------------------------------------------*
* TIMER file contains                                                                                           *
*                                                                                                               *
* - The used DRIVER and TRACE in case of GENERAL translation                                                    *
* - The TIMER variables used in both translation modes                                                          *
* - Additional TIMER variables in case of GENERAL translation                                                   *
* - The WEATHER control variables if weather data are used                                                      *
* - Miscellaneous FSE variables in case of FSE translation                                                      *
*                                                                                                               *
* File: VALLA.FOR                                                                                               *
* Date: 09-08-97                                                                                                *
* Time: 15:40:06                                                                                                *
*                                                                                                               *
* TIMER variables used in GENERAL and FSE translation modes                                                     *
* ---------------------------------------------------------------------------------------------------------------*
  STTIME        = 1.        ! start time
  FINTIM        = 365.      ! finish time
  DELT          = 1.        ! time step (for Runge-Kutta first guess)
  PRDEL         = 1.        ! output time step
  IPFORM        = 4         ! code for output table format:
                            ! 4 = spaces between columns
                            ! 5 = TAB's between columns (spreadsheet output)
                            ! 6 = two column output

                            ! The string array PRSEL contains the output variables for
                            ! which formatted tables have to be made. One or more times
                            ! there is a series of variable names terminated by the word
                            ! <TABLE>.
                            ! The translator writes the variables in each PRINT statement
                            ! to a separate table.
  PRSEL =
* 'DAVTMP',
* 'DAYL  ',
* 'DDTMP ',
* 'DTEFF ',
* 'DTGA  ',
* 'DVS   ',
* 'FGROS ',
* 'GPHOT ',
* 'IRS   ',
* 'MAINT ',
  'NDTUB ',
* 'NGTUB ',
* 'NNTUB ',
* 'NTM   ',
* 'NTUBD ',
* 'NTUBPD',
* 'REMOB ',
*  'TEFF ',
  'TGW   ',
* 'TGWM  ',
* 'TRANS ',
* 'TREMOB',
* 'TW    ',
* 'TWGTUB',
* 'TWLVD ',
* 'TWLVG ',
* 'TWNTUB',
* 'TWRTD ',
  'TWRTG ',
* 'TWSTD ',
* 'TWSTG ',
* 'TWTUB ',
* 'TWTUBD',
```

```
*'WTMP ',
      '<TABLE>'
 COPINF = 'N'        ! Switch variable whether to copy the input files
                     ! to the output file ('N' = do not copy,
                     ! 'Y' = copy)
 DELTMP = 'N'        ! Switch variable what should be done with the
                     ! temporary output file ('N' = do not delete,
                     ! 'Y' = delete)
 IFLAG  = 1101       ! Indicates where weather error and warnings
                     ! go (1101 means errors and warnings to log
                     ! file, errors to screen, see FSE manual)
*IOBSD = 1991,182   ! List of observation data for which output is
                     ! required. The list should consist of pairs
                     ! <year>,<day> combination


* WEATHER control variables
* -------------------------------------
 WTRDIR        =       'C:\WILDCEL\WEATHER\'
 CNTR          =       'USA'             ! Country code
 ISTN          =       6                 ! Station code
 IYEAR         =       1978              ! Year
```

Example of RERUNS.DAT File

```
*-----------------------------------------------------------------------------------------------*
* RERUNS file ... to produce multiple runs ...                                                  *
* File: VALLA.FOR                                                                               *
* Date: 09-12-95                                                                                *
* Time: 11:00:00                                                                                *
*-----------------------------------------------------------------------------------------------*

* RERUNS variables used in GENERAL and FSE translation modes
* ----------------------------------------------------------------------------
YRNUM           = 2.         ! 2nd year of simulation
HAR             = 1.         !1=YES, harvesting does occur
HARDAY          = 74.        ! Harvesting occurs on Julian day number 74
HARDEP          = 1.0        ! Harvesting depth is 1.0 m
YRNUM           = 3.         ! 3rd year of simulation
HAR             = 1.         ! 1=YES, harvesting does occur
HARDAY          = 181.       ! Harvesting occurs on Julian day number 181
HARDEP          = 0.5        ! Harvesting depth is 0.5 m
```

Example of CONTROL.DAT file

```
*---------------------------------------------------------------------------------------------------*
* CONTROL.DAT data file contains:                                                                   *
*      - File names to be used by FSE 2.1                                                           *
*      - The input files (except FILEIR) may be used in reruns; up to                               *
*        five input data files may be used (FILEI1-5)                                               *
*---------------------------------------------------------------------------------------------------*

  FILEON        = 'RES.DAT'        ! Normal output file
  FILEOL        = 'MODEL.LOG'      ! Log file
  FILEIR        = 'RERUNS.DAT'     ! Reruns file
  FILEIT        = 'TIMER.DAT'      ! File with timer data
  FILEI1        = 'MODEL.DAT'      ! First input data file

* FILEI2        = ' '             ! Second input data file (not used)
* FILEI3        = ' '             ! Third input data file (not used)
* FILEI4        = ' '             ! Fourth input data file (not used)
* FILEI5        = ' '             ! Fifth input data file (not used)
```

Example of RES.DAT File

```
*-------------------------------------------------------------------*
* Output table number  :  0 (=first output table)        *
* Output table format  : Table output                    *
* Simulation results                                     *
*-------------------------------------------------------------------*

        TIME      NDTUB       TGW

       1.00000    233.00     .00000
       2.00000    231.95     .00000
       3.00000    230.91     .00000
       4.00000    229.87     .00000
       5.00000    228.83     .00000
       6.00000    227.80     .00000
       7.00000    226.78     .00000
       8.00000    225.76     .00000
       9.00000    224.74     .00000
      10.0000     223.73     .00000
          .          .         .
          .          .         .
     363.000      122.33     8.6301
     364.000      121.78     8.4910
     365.000      121.19     8.3485
```

Weather Data File Provided

```
*----------------------------------------------------------------------------*
* Country: United States of America                                          *
* Station: Binghamton,NY (Solar & wind from Ithaca, NY)                      *
* Year: 1978                                                                 *
* Source: Cornell University                                                 *
*  Author: Jeffrey Schultz                                                   *
*  Longitude: 75 50 W                                                        *
*  Latitude: 42 15 N                                                         *
*  Elevation: 000 m.                                                         *
*  WMO-code: - ;US station code 4174, in this file changed to 1             *
*          Phone 607-255-1751 .. ftp//:mist.cit.cornell.edu                 *
*  Comments: Data obtained from Jeffrey Schultz (Cornell University, Ithaca, NY) *
*         Converted and arranged into weather files by Will Boyd (1997)      *
*         Elevation listed as 0 because unknown to us                        *
*  Columns:                                                                  *
*  ========                                                                  *
*  station number                                                            *
*  year                                                                      *
*  day                                                                       *
*  irradiation (kJ m-2 d-1)                                                  *
*  minimum temperature (degrees Celsius)                                     *
*  maximum temperature (degrees Celsius)                                     *
*  vapour pressure (kPa)                                                     *
*  mean wind speed (m s-1)                                                   *
*  precipitation (mm d-1)                                                    *
*----------------------------------------------------------------------------*
     75.83 42.25       000.          0.00        0.00
   1    1978    1       2806.   -10.6    -3.3    .000     2.4     3.6
   1    1978    2       4397.   -10.0    -3.3    .000     2.7     1.0
   1    1978    3       5067.   -13.3    -8.3    .000     3.1      .3
   1    1978    4       6994.   -12.2    -3.9    .000     3.3     0.0
   1    1978    5       7161.    -3.9     .0     .000     2.4      .0
   1    1978    6       2010.    -1.7    1.7     .000      .8     0.0
   1    1978    7       2973.    -1.7     .0     .000     1.2     4.8
   1    1978    8       1591.     -.6   10.6     .000     5.5    14.5
   1    1978    9       1173.   -15.0   11.1     .000     6.1    20.6
   1    1978   10       3099.   -15.6   -10.6    .000     4.9     7.4
   1    1978   11       2806.   -11.7    -7.2    .000     6.2     0.0
   1    1978   12       6366.   -11.7    -6.1    .000     3.3      .3
   1    1978   13       4356.    -7.8    -4.4    .000     1.3     3.3
   1    1978   14       3099.   -12.8    -5.0    .000     2.3    11.9
   1    1978   15       2052.   -13.9   -10.0    .000     3.2     0.0
   .       .    .          .       .       .       .       .       .
   .       .    .          .       .       .       .       .       .
   .       .    .          .       .       .       .       .       .
   1    1978  363       3350.   -15.0    -6.7    .000     2.4     0.0
   1    1978  364       6575.   -10.0     -.6    .000     1.3      .0
   1    1978  365       4272.    -1.7    5.0     .000     4.6     3.0
```

* Note: Longitude and latitude in the header are listed in degrees and minutes while they are listed in degrees only on the first line of the weather data.

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*

This manual has been written as a practical guide for the operational use of VALLA (Version 1.0), a personal computer-based software package that simulates growth of American wildcelery. This manual includes instructions for installing and using the VALLA software package as well as example runs to provide further information to facilitate proper execution and to demonstrate applications.

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