**US Army Corps
of Engineers**®
Engineer Research and
Development Center

Aquatic Plant Control Research Program

POTAM (Version 1.0): A Simulation Model for Growth of Sago Pondweed

Elly P. H. Best and William A. Boyd   July 2003

20030909 058

POTAM (Version 1.0): A Simulation Model for Growth of Sago Pondweed

Elly P. H. Best, William A. Boyd

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

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

Contents

List of Figures

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) under the purview of the Environmental Laboratory (EL). The UMR-IWW System Navigation Study is being conducted by the U.S. Army Engineer Districts of 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. Mr. Robert C. Gunkel, Jr., was Program Manager, APCRP. Technical Monitor during this study was Mr. Timothy Toplisek, HQUSACE.

The work described herein was performed at ERDC, EL, Environmental Processes and Engineering Division (EPED), by Dr. Elly P. H. Best, Environmental Risk Assessment Branch (ERAB), with programming assistance from Mr. William A. Boyd, Ecosystems Processes and Effects Branch (EPEB). Ms. Anne B. Stewart, Dyntel Corporation, assisted with the graphics. Dr. Best and Mr. Boyd prepared this report. Dr. David Spencer, U.S. Department of Agriculture - Agricultural Research Service, Weed Science Program, University of California, Davis, California, provided an external technical review. The report was reviewed internally by Mr. W.F.James, Ecosystem Processes Branch, and Dr. Gregory A. Kiker (EPED).

This investigation was performed under the direct supervision of Dr. Lance D. Hansen, Chief, ERAB, and the general supervision of Dr. Richard E. Price, Chief, EPED, and Dr. Edwin A. Theriot, Director, EL.

COL John W. Morris III, EN, was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1   Introduction

A simulation model for biomass dynamics of a submersed sago pondweed vegetation has been developed and called POTAM. 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 the site can be easily modified by the user. POTAM is based on modeling concepts and approaches similar to those used to model three other submersed macrophytes, hydrilla (HYDRIL) (Best and Boyd 1996; Boyd and Best 1996), Eurasian watermilfoil (MILFO) (Best and Boyd 1999a,b), and American wildcelery (VALLA) (Best and Boyd 2001a,b).

POTAM incorporates insight into the processes affecting dynamics of a Sago pondweed community in relatively shallow, hard water (0.1- to 6-m depth; dissolved inorganic carbon (DIC) concentration > 0.8 mmol and pH > 6). It has been calibrated on data pertaining to a sago pondweed community in the Western Canal near Zandvoort, The Netherlands. At this site, with a temperate climate as found in Maine, USA, 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. The latter carbohydrates are used for the formation of tubers that grow into the sediment.

POTAM accurately simulated the dynamics of plant and tuber biomass in the Western Canal 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 Veluwe (The Netherlands) and the Byrnes Canal (California), both with temperate climates, and Lake Ramgarh (India), with a tropical climate.

Sensitivity analysis showed that maximum plant biomass of a sago pondweed community is most sensitive to a change in photosynthetic activity at light saturation but not to a change in light use efficiency. Maximum plant biomass was also strongly affected by changes in preanthesis development rate. End-of-year tuber number was sensitive to seven out of nine parameters tested. Sensitivity was greatest to changes in preanthesis development rate.

Environmental factor analysis indicated that maximum plant biomass was sensitive to changes in climate.

POTAM can be used as a tool to predict the dynamics of a sago pondweed 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 (technical report in preparation).

2 Installation and Execution of the Model

System Requirements

There are few requirements for running POTAM (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 POTAM (Version 1.0)

The model uses the DOS operating system. To switch from the WINDOWS to the DOS operating system, double-click on the Windows START button to access the system drop-down menu, double-click START RUN, Type CMD, and click ENTER. The initial step to install POTAM is to create a new directory, with the name SAGO, using the DOS command MKDIR. For example, the DOS command MKDIR C:\SAGO creates a new directory on the C drive called SAGO. Copy the contents of the floppy diskette to the directory C:\SAGO by using the following command:

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

This diskette contains the POTAM.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 POTAM model

or may choose to create a weather file specific to a particular site. 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 A.

Executing POTAM (Version 1.0)

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

POTAM <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 POTAM (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.

Subroutines called during the execution of the POTAM 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 and is where specific calculations for sago pondweed 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 and 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   │   │   subroutine   │   │    subroutine      │
│     ASTRO      │   │     TOTASS     │   │      ASSIM         │
│  * Photoperiod │   │                │   │ * Light attenuation│
│                │   │ * Daily total  │   │   water + vegetation│
│  * Daylength   │   │   gross        │   │ * Instantaneous    │
│                │   │   assimilation │   │   gross assimilation│
│  * Irradiation │   │   (3-point     │   │   (0.1-m depth     │
│                │   │   Gaussian     │   │    layers)         │
│                │   │   integration) │   │                    │
└────────────────┘   └────────────────┘   └────────────────────┘
```
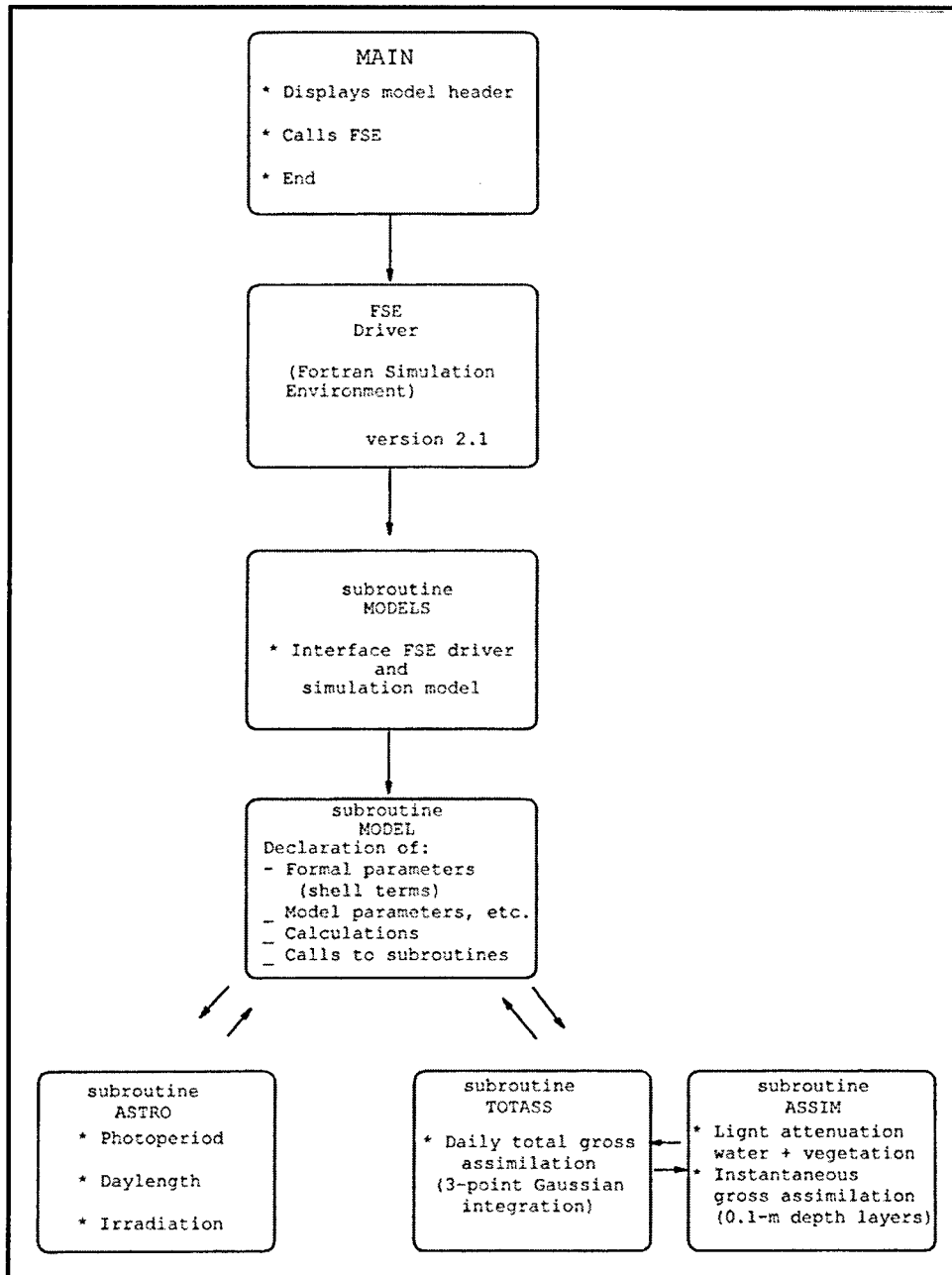
Figure 1.   Relational diagram of POTAM and its subroutines in combination with
the FSE shell

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 POTAM 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 POTAM are discussed in this section.

Input files

MODEL.DAT file

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

TIMER.DAT file

The data file TIMER.DAT 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 also shown in Appendix A.

RERUNS.DAT file

If the RERUNS.DAT 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.

CONTROL.DAT file

The CONTROL.DAT file contains the names of both input and output files used during the execution of POTAM. An example of the CONTROL.DAT file is shown in Appendix A.

Output files

POTAM creates three standard output files with a potential fourth, binary file: RES.DAT, MODEL.LOG, WEATHER.LOG, and RES.BIN.

RES.DAT file

The RES.DAT 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 A).

MODEL.LOG file

The MODEL.LOG 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.

WEATHER.LOG file

The WEATHER.LOG 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.

RES.BIN file

The variable DELTMP found in the TIMER.DAT file (Appendix A) 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-PCs 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 below.

Weather Data Files

The weather data system basically consists of two parts: the 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., NLD4.987 applies to data from the Dutch (NLD) meteorological station in De Bilt (4) for the year 1987).

Daily values are provided for the weather parameters in the tabulation below:

Name Parameter	Unit
Global radiation (daily total)	$KJ/m^2/d$
Minimum air temperature	°C
Maximum air temperature	°C
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 A.

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 POTAM 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 POTAM (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. POTAM can rapidly provide information on the growth and development rate of sago pondweed over a specified period. Model output parameters are presented in Appendix B.

Example 1: Nominal run

The current MODEL.DAT file (Appendix A) contains data required to execute a nominal run. In the section "Initial constants" of the MODEL.DAT file, all initial plant biomass values are set to zero, except that of the initial dry weight of individual tubers (INTUB). 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 0.083 g DW (Spencer and Anderson 1987). Other characteristics of the tuber bank used for this run are listed in the section "Model parameters." These parameters are: the tuber bank density (NDTUB) set at 240 tubers per m^{-2} (Best et al. 1987), and the standard plant density (NPL) set at 30 plants per m^{-2} (Best et al. 1987, unpublished; Van Wijk 1989).

In the MODEL.DAT file under the section "Initial constants" (Appendix A) only the initial dry weight of individual tubers has a value > 0; i.e., of 0.083 g DW. All weights of other plant parts are initialized at 0. This run describes the typical behavior of a sago pondweed vegetation in temperate regions 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 per m^2 on day 1 of the simulation. The simulation is executed for 1 full year using weather data contained in the file NLD4.987. This file contains weather data obtained from the weather station at De Bilt (irradiance, minimum and maximum air

temperature, vapor pressure, and wind speed), The Netherlands, 1987; the file is located on the subdirectory C:\SAGO\WEATHER.

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

CD/SAGO <CR>

and then type

POTAM <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, POTAM lists the names and contents of output files created. Results of this simulation are discussed in paragraph "Example Output," this chapter, page 15.

Example 2: Initial biomass >0.0 g

In Example 2, an almost identical MODEL.DAT file (Appendix A) 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 with wintering plants present may occur in deeper, clear waters in temperate regions (Hammer and Heseltine 1988). Plant biomass is partitioned over the leaves, stems, and roots as follows. Of the total plant live weight, 80.0 percent is in the leaves, 12.5 percent in the stems, and 7.5 percent in the roots (Best et al. 1987, unpublished; Sher Kaul et al. 1995). The weights are calculated below:

IWLVG = 0.80 × 20 = 16.00   ! Initial dry matter of live leaves
                                          ! (g $DW.m^{-2}$)

IWRTG = 0.075 × 20 = 1.50   ! Initial dry matter of live roots
                                          ! (g $DW.m^{-2}$)

IWSTG = 0.125 × 20 = 2.50   ! Initial dry matter of live stems
                                          ! (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 POTAM 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., MODELP0.DAT. Each POTAM run uses

only 'the' MODEL.DAT file as input (so, make sure you only have one MODEL.DAT file in the SAGO directory). For simulation results, see "Example Output," this chapter, page 15.

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

In Example 3, an almost identical MODEL.DAT file (Appendix A) is used as for the nominal run. This run begins with 20 g DW live plant biomass (excluding tubers) per m^{-2} and a smaller tuber size (of 0.070 g DW per tuber^{-1}) than in the nominal run on day 1 of the simulation. A situation like this may occur in shallow water bodies in relatively warm, temperate climates where often smaller tubers are produced (Pilon 1999). Tuber banks with decreased tuber densities may occur in situations where tubers have been grazed by waterfowl (Korschgen et al. 1988; Korschgen 1989; Kantrud 1990). Results of these simulations are discussed on page 15 in the section "Example Output." The run is started from the same plant biomass as used in Example 2; i.e., wintering plants. Furthermore, the initial dry weight of a tuber under the section "Initial constants," and the tuber bank density (dormant tuber number) under "Model parameters" have been changed.

Individual tuber weight and tuber number concurrently initiated formed 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 (Spencer and Anderson 1987). The tuber weight used in the nominal run is representative for the light level in the calibration situation. However, light levels experienced by a sago pondweed vegetation at other sites can be higher or lower, and consequently tuber behavior has to be modified to apply to those situations. For instance, in a case where it is known that a tuber size of 0.07 g DW per tuber is representative the following changes have to be made in the MODEL.DAT file.

In "Initial constants":

    INTUB = 0.07   ! Initial dry weight of a tuber
                               ! (g DW.m^{-2})

In "Model parameters":

    NINTUB = 6   ! Tuber number concurrently initiated per plant
                               ! (g DW.m^{-2}); read from Figure 2

    SURPER = 22.8   ! Survival period of tubers (d); calculated as
                               ! (0.07 (new INTUB value)/0.083(nominal INTUB value))
                               ! × 27 (nominal SURPER value)

    TWCTUB = 12.6   ! Total critical dry weight of new tubers
                               ! (g DW.m^{-2}); calculated as
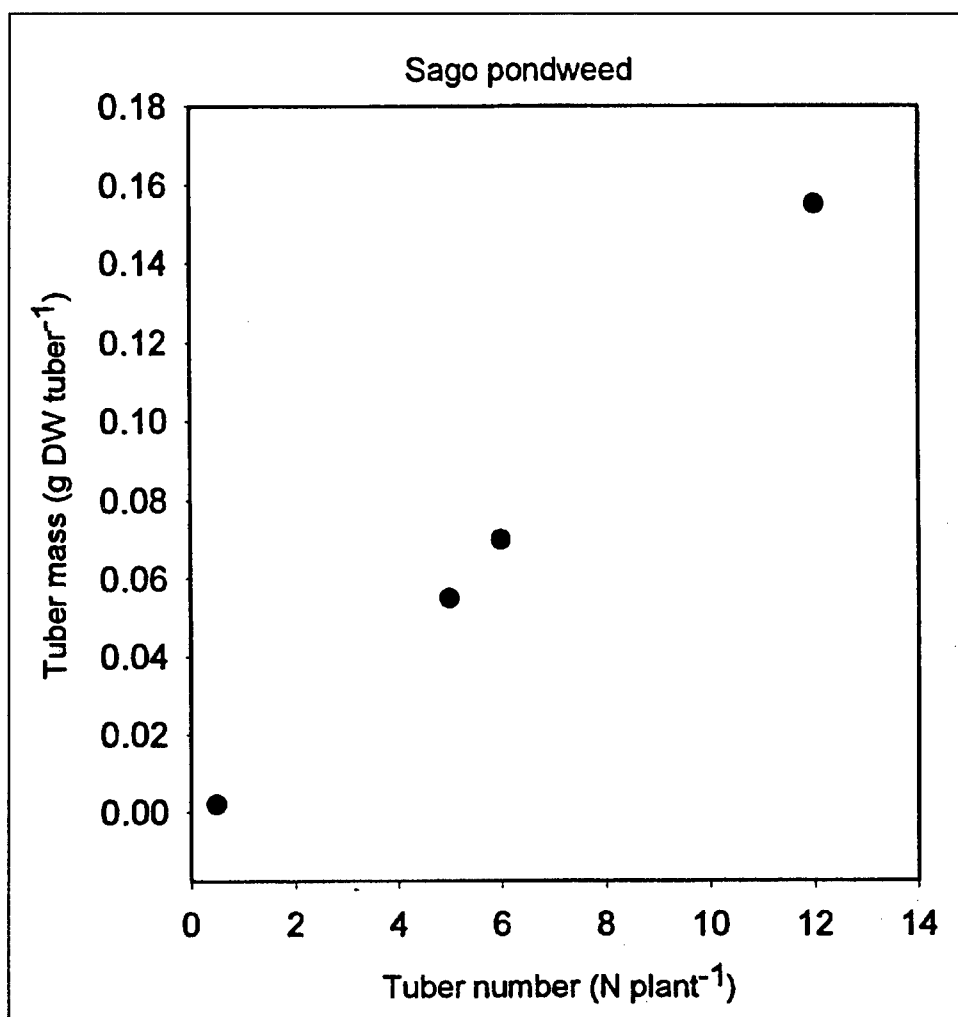   ! 0.07 (INTUB) × 6 (NINTUB) × 30 (NPL)

Figure 2. The relationship between tuber number concurrently initiated per plant and tuber size for sago pondweed (after Spencer and Anderson 1987)

When starting the simulation with a tuber bank density <30 tubers/m^{-2}; e.g., 18 tubers, only 18 tubers can sprout and develop into plants, and plant density (NPL) then has to get the value of 18 in the predefined model parameter TWCTUB. Since the critical dry weight of new tubers (TWCTUB) is a function of plant density, the 'new' NPL value of 18 has to be used to recalculate the inherent value of TWCTUB. The latter value would then become 7.56 (0.07 × 6 × 18).

Example 4: Sago pondweed populations at different water depths

Example 4 uses a MODEL.DAT file 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" (Appendix A) have been changed for three separate runs, respectively; i.e., to 0.2-m and 5-m depth (1.3 m is nominal depth).

Changing this parameter set enables running the model for a sago pondweed stand:

- 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.
  Nominal: DPTT = 1., 1.3, 365., 1.3
  Constant water depth of 0.2 m: DPTT = 1., 0.2, 365., 0.2

- 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).
  Fluctuating water depth: DPTT = 1., 0.2, 3., 0.5, 10., 1.0, 365., 0.2

Data pairs have to 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 a change in constant water depth are presented in the section "Example Output," following Example 5.

Example 5: Sago pondweed populations in water bodies with different transparencies

Example 5 uses a MODEL.DAT file 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" (Appendix A) have to be changed. Data pairs have to 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.

Nominal: LT = 1., 1.07, 365., 1.07
More turbid: LT = 1., 2.0, 10., 2.5, 150., 3.0, 365., 2.0

Changing this parameter set enables running the model for the same sago pondweed stand in a water for different years with annually and/or seasonally changing light extinction coefficients, and/or for different sago pondweed stands in lakes differing in water transparency. Water transparency values, expressed in Secchi depth (in meters), should be converted to light extinction coefficients (1 per 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 (USEPA 1992).

Example Output

The output of Example run 1 is presented in Figure 3, Example runs 2 and 3 in Figure 4, Example run 4 in Figure 5, and Example run 5 in Figure 6.
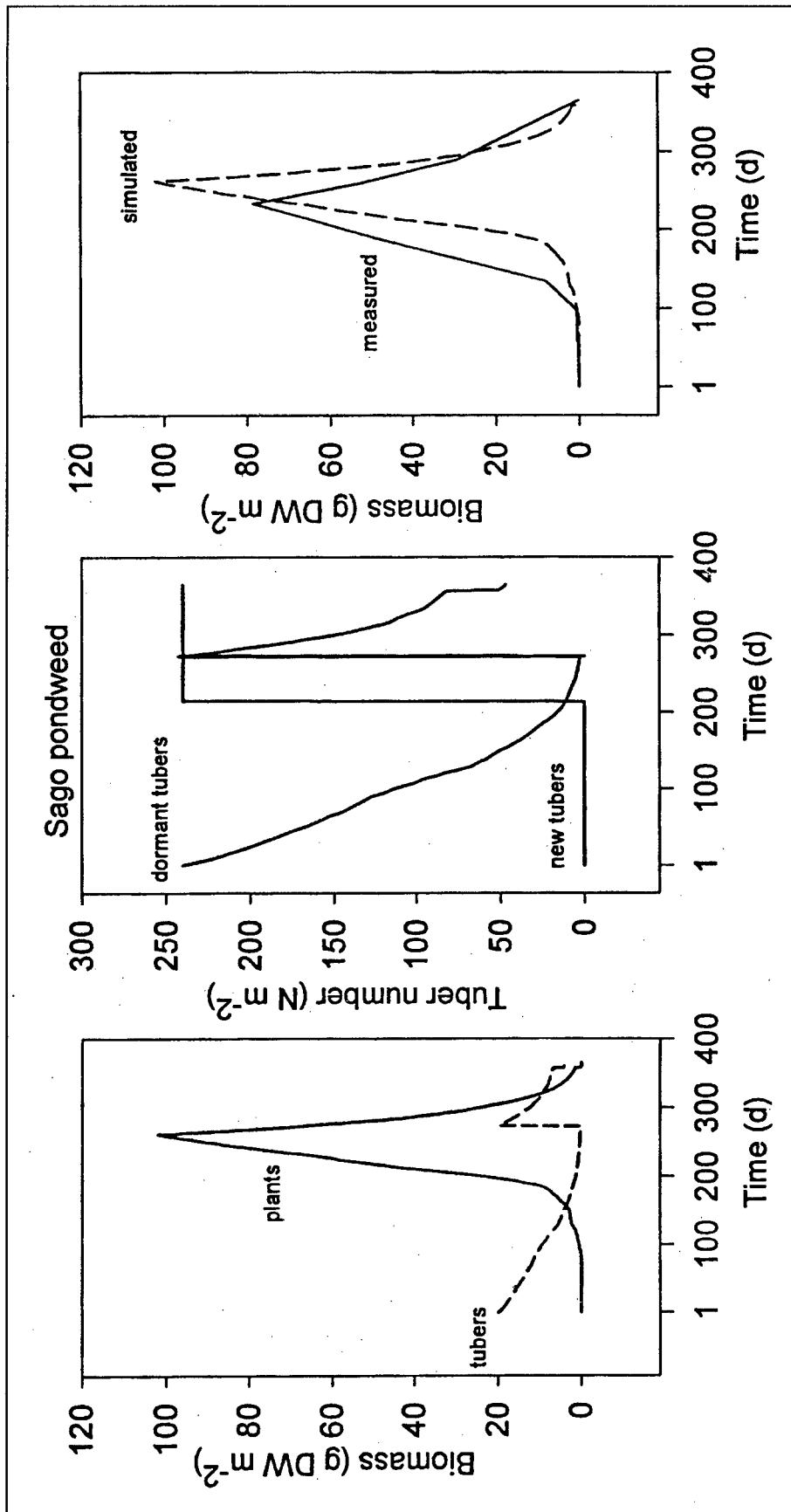
Figure 3. Simulated biomass of plants, dormant and new tuber numbers, and measured plant biomass of a sago pondweed community in the Western Canal near Zandvoort, The Netherlands. Nominal run. Field data from Best et al. (1987); climatological data 1987, De Bilt, The Netherlands (longitude 05° 11' E, latitude 52° 06' N); water depth 1.3 m; light extinction coefficient 1.07 m⁻¹
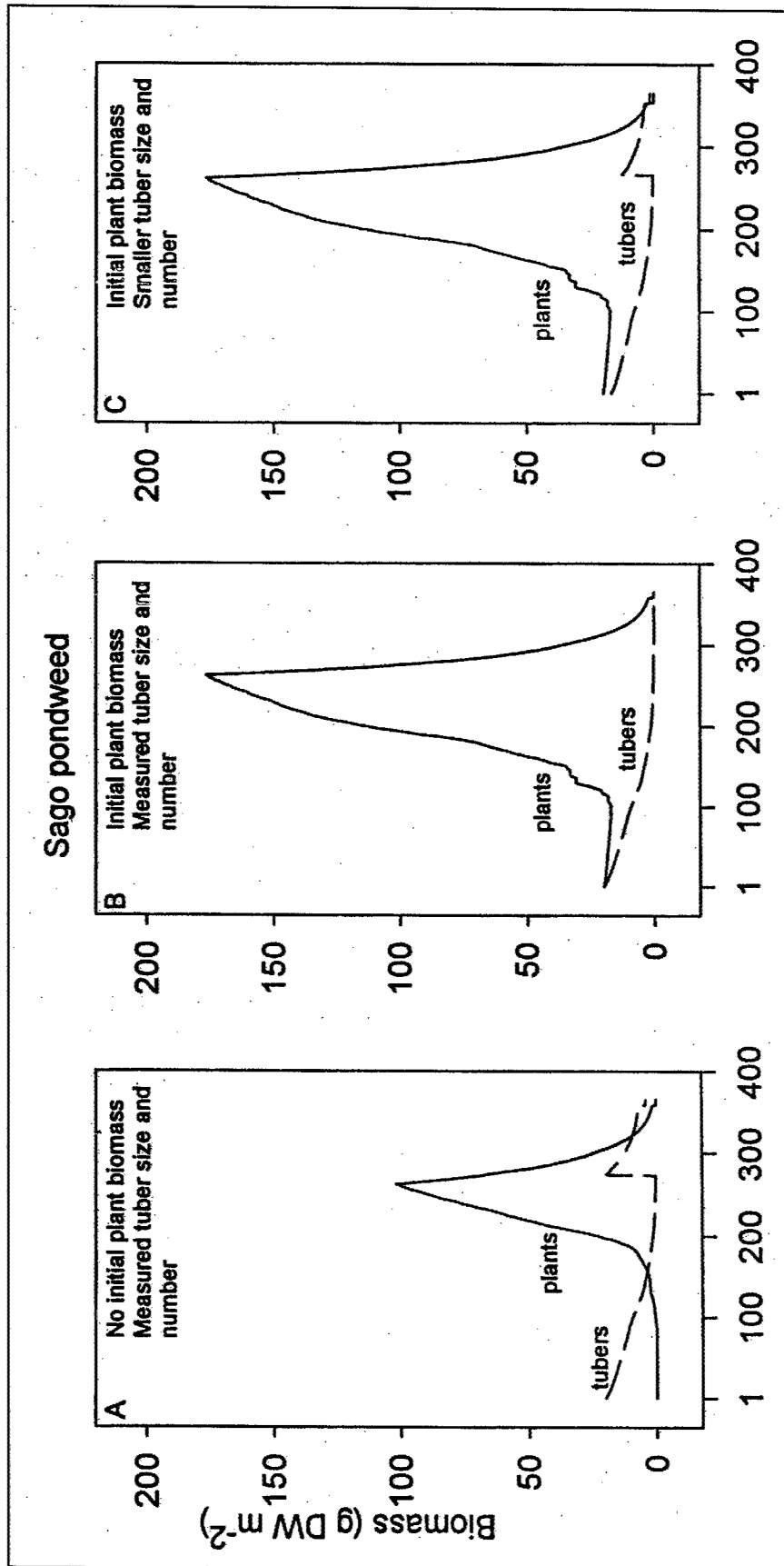
Figure 4. Simulated biomass of plants and tubers of sago pondweed community in the Western Canal near Zandvoort, The Netherlands, started from different initial biomass conditions but run in the same environmental and climatological, nominal, conditions. (A) Plant biomass 0; tuber size 0.083-g DW; tuber bank 240 m^{-2}. (B) Plant biomass 20-g DW m^{-2}; tuber size 0.083-g DW; tuber bank density 240 m^{-2}. (C) Plant biomass 20-g DW m^{-2}; tuber size 0.070-g DW; tuber bank density 240 m^2

Figure 5. Simulated biomass of plants and tubers of sago pondweed community in the Western Canal near Zandvoort, The Netherlands, 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 50 m^{-2}
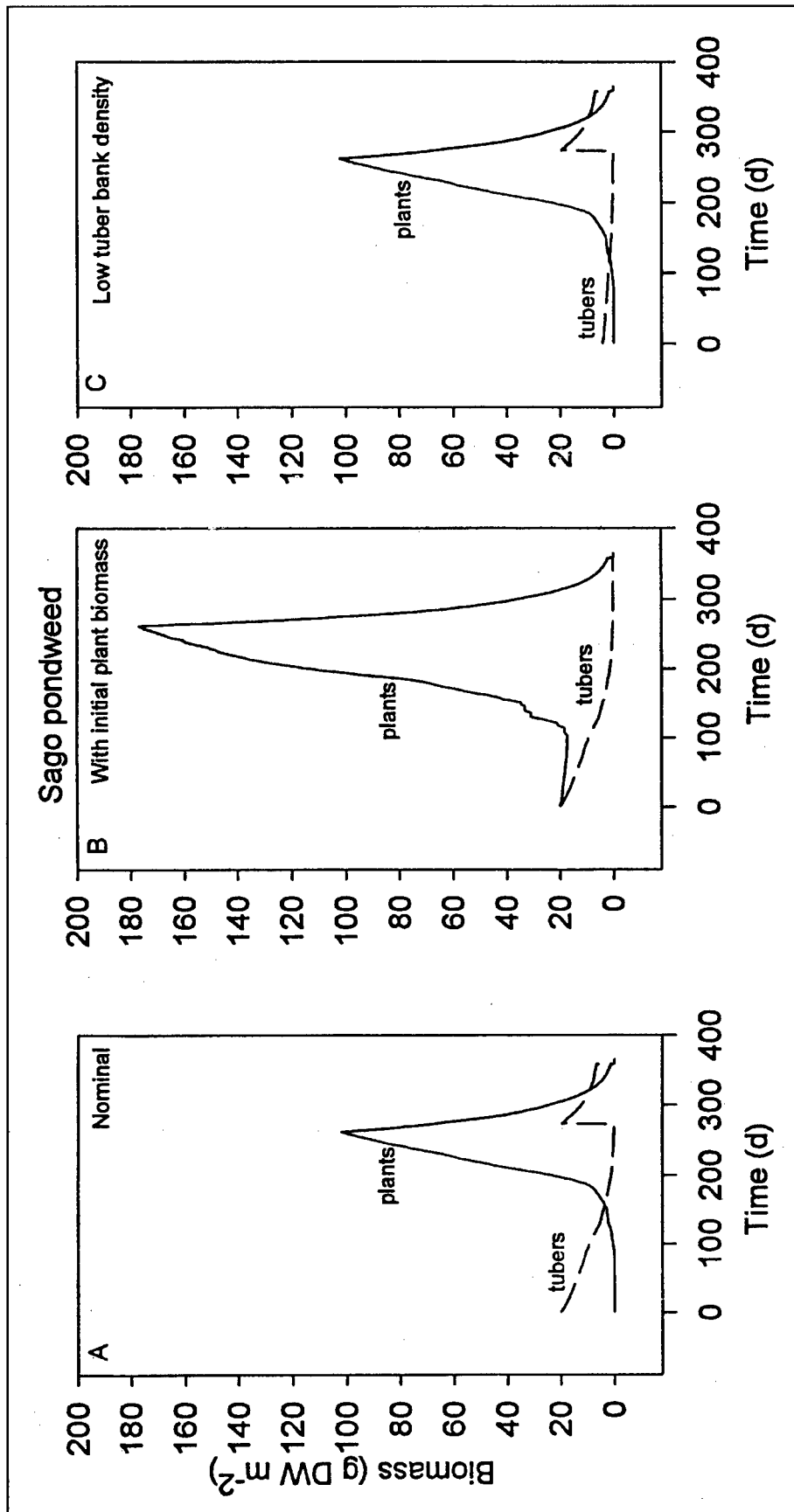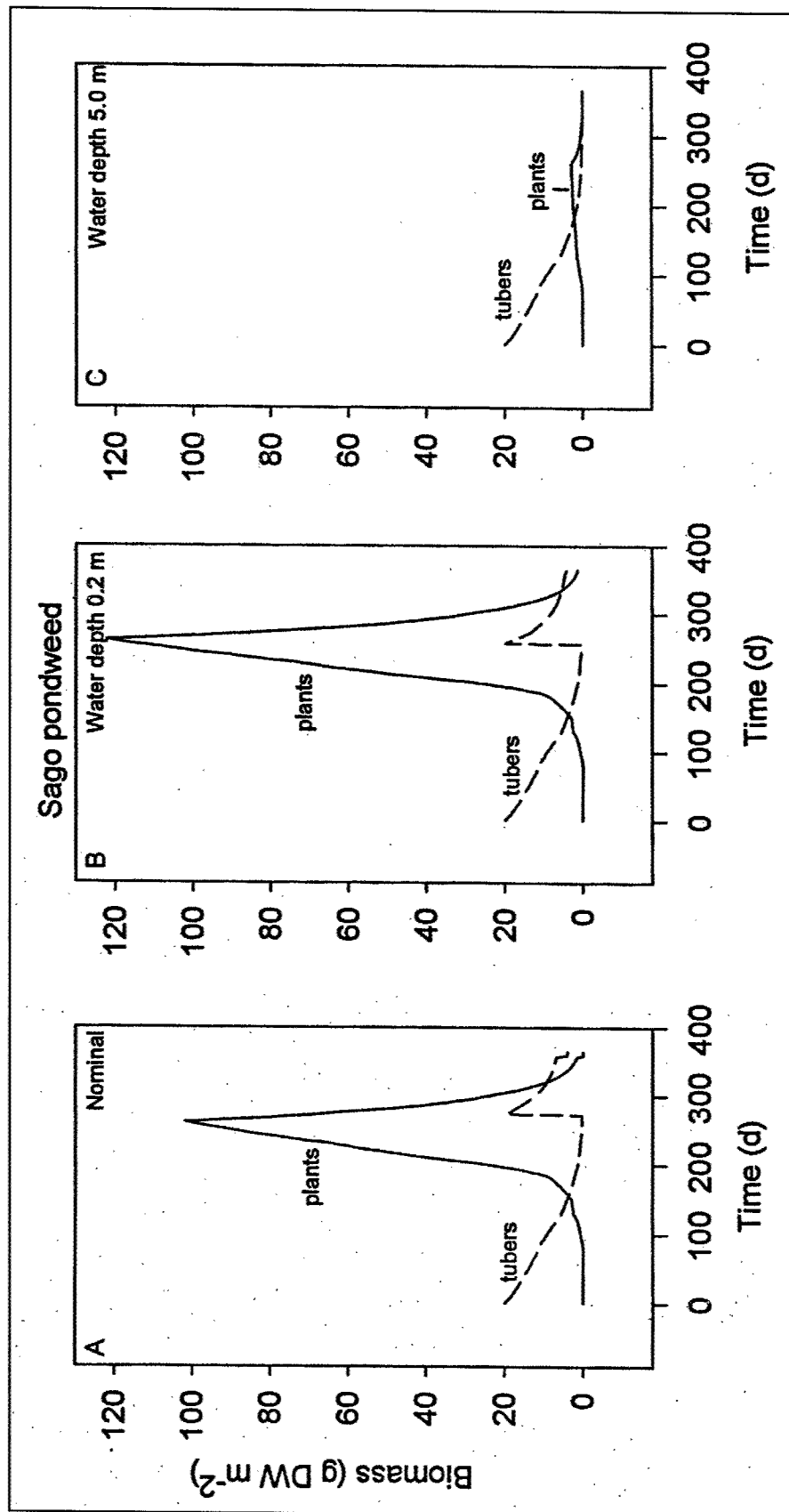
Figure 6.   Simulated biomass of plants and tubers of sago pondweed community in the Western Canal near Zandvoort, The Netherlands, started from nominal initial data, and (A) 1.3-m water depth; (B) 0.2-m water depth; (C) 5-m water depth

All output parameters listed in Appendix B 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, e.g., the total live plant biomass 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. The variable would be TW; for the accumulated live + dead biomass; the variables would be TWLG, TWST, TWRG; for the live weights of the plant organs; and TWLD, TWSD, TWRD for their dead weights.

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 83 onward. Plant biomass peaked on day 262 at 101.9 g DW.m^{-2}. The simulated tuber weight decreased from 20 g DW.m^{-2} on day 1 onward to 0, until new tubers were formed (from day 272 onward). Once finished, each tuber class is added to the tuber bank, which loses weight by senescence. One tuber class was complete at the end of the year. Tuber classes and numbers can be followed also. Simulated plant biomass lagged 13 days behind and exceeded measured plant biomass slightly.

Total plant biomass of sago pondweed was usually higher for the run with initial plant biomass present than for the nominal run (Figures 4A, B, C). Live plant biomass peaked at day 262 with 176.8 g DW.m^{-2} in the run with initial plant biomass, and with 101.2 g DW.m^{-2} in the nominal run. No tuber class was finished in the population with initial plant biomass present and started from the nominal tuber size. However, one tuber class was finished in the population with initial plant biomass present and started from a smaller tuber size (Figure 4C). 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 nominal and with low tuber bank density (Figures 5A and C). 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 50 m^{-2} at day 1 can generate 30 full-grown plants under the chosen environmental (weather, water depth and trans-parency) conditions. At tuber bank densities <30 tubers/m^{-2} at day 1 (e.g., 15), the model resets the plant density to 15 m^{-2} and uses the latter number in the run. An example tropical weather file is shown in the tabulation on page 21.

The output of Example run 5 is presented in Figure 6. Simulated live plant biomass increased somewhat with decreasing anchorage depth, but tuber production was similar at the shallow (0.2 m) and nominal anchorage depth (1.3 m). However, at 5-m anchorage depth, barely any plant biomass was formed and no tubers were produced.

Use of Different Weather Files

Climate is an important factor influencing sago pondweed 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 sago pondweed, POTAM was executed using weather files representing a cool temperate, a warm temperate, and a tropical climate, respectively.

The same nominal MODEL.DAT file (Appendix A) was used as the basis for biomass-specific input data. For the nominal run the file was used unchanged. For the California run, a lower self-shading coefficient (K-value), smaller tuber size, lesser anchorage depth, and lower light extinction coefficient of the water column were entered into the MODEL.DAT file. In clear water, sago pondweed tends to have a lower plant species specific light extinction coefficient (K value of 0.0183 m^2 g DW^{-1}) (Westlake 1964; Sher Kaul et al. 1995) than found in the more turbid conditions of the Western Canal, The Netherlands (K value of 0.095 m^2 g DW^{-1}) (Best et al. 1987). For the India run, only the K-value was changed in the nominal MODEL.DAT file. The TIMER.DAT file specified for the nominal run is the temperate weather file (NLD4.987); for the California run, the warm-temperate weather file (USA7.990); and for the tropical run, the tropical file (IND1 978). Each weather file is described below:

Cool-Temperate (nominal) Weather File
Country: The Netherlands
Station: De Bilt
Year: 1987
Longitude: 5° 11' E
Latitude: 52° 06' N
Elevation: 4 m

Warm-Temperate Weather File
Country: USA
Station: Davis
Year: 1990
Longitude: 121° 47' W
Latitude: 38° 32' N
Elevation: 180 m

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

Figure 7 shows output of the three simulations of live plant and tuber biomass in the three different climates over a 1-year period. Apparently, sago
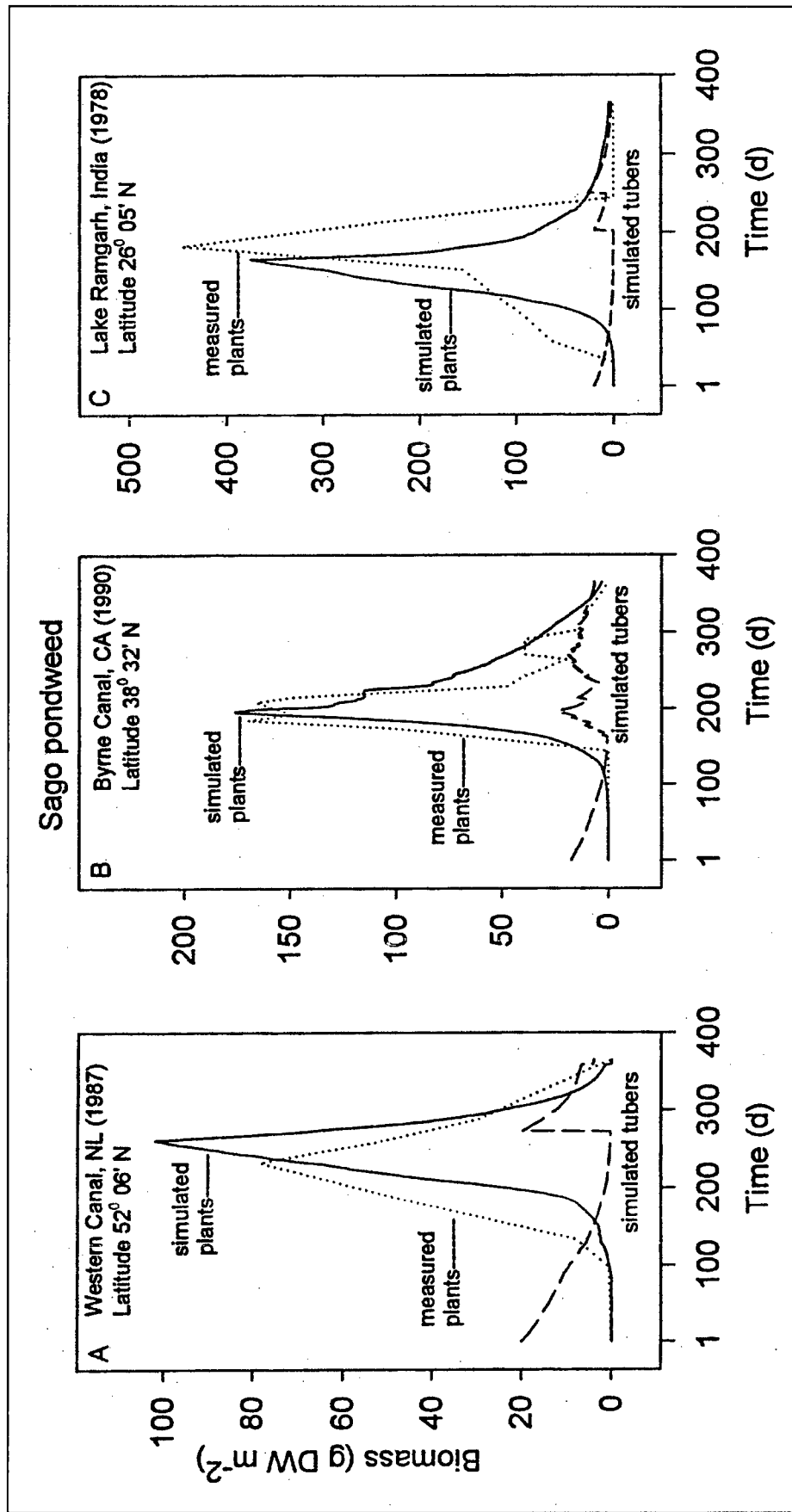
Figure 7. Simulated biomass of plants and tubers of sago pondweed community at sites differing in latitude. (A) The Western Canal near Zandvoort, The Netherlands (longitude 05° 11' E, latitude 52° 06' N; tuber size 0.083-g DW, tuber bank density 240 m^{-2}, water depth 1.3 m; light extinction coefficient 1.07 m^{-1}; climatological data 1987, validation data 1987 (Best et al. 1987)); (B) Byrne Canal, CA (longitude 121° 47' W, latitude 38° 32' N; tuber size 0.025-g DW, tuber bank density 700 m^{-2}, K-value 0.0183-m^2/g DW^{-1}, water depth 0.2 m; light extinction coefficient 0.4 m^{-1}; climatological data 1990; validation data 1990, (Spencer unpubl.)); (C) Lake Ramgarh, India (longitude 83° 26'E, latitude 26° 05' N; tuber size 0.083-g DW, tuber bank density 240 m^{-2}. K-value 0.0183-m^2/g DW^{-1}, water depth 1.3 m; light extinction coefficient 1.07 m^{-1}; climatological data Patancheru, India, 1978 (longitude 78° 28' E, latitude 17° 27' N); validation 1968 (Sahai and Sinha (1973))

pondweed communities in warm temperate climates produce more plant biomass and numerous small tubers. In tropical climates, however, these communities produce high plant biomass and very few tubers as a result of the small window in time that is potentially available for their initiation. The third example of the sago pondweed community shown in Figure 7 is further illustrated and discussed by Best and Boyd (2003).

Removing Plant Biomass By Mechanical Harvesting

POTAM can also be used to calculate effects of various control methods on biomass and survival of a sago pondweed 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 (Appendix A), 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 no. 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 in section "Simulated behavior of a sago pondweed community subject to biomass removal; effects of mechanical harvesting and grazing" by Best and Boyd (2003).

Multiple Year Runs

POTAM 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 A of this manual. 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 A).

5 Running the Model Within a Shell

This chapter gives a brief description of how the FSE shell drives the POTAM model. All execution starts with a MAIN program (Figure 1). This is a short program which 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 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 POTAM 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 POTAM are:

a. Phenology is tied indirectly to 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 or water temperatures must be used to run the model. When air temperatures are used, the lag period between air and (calculated) water temperatures can be varied between 1 and 7 days; this is an important feature for application in water bodies varying in depth, with large groundwater inputs, etc.

f. The model can be used for communities at water depths that can vary between years and daily within the year. This is an important feature for application in reservoirs and rivers.

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

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

7 Application Possibilities

POTAM can be used to assess behavior of a sago pondweed 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 (e.g., Bartell et al. 2000).

The present version of POTAM (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. A similar growth model, developed for American wildcelery, has been used to calculate the potential production of plant biomass and tubers in Peoria Lake, Illinois. This growth model includes data on hydrodynamics as inputs and plant parameter outputs spatially visualized through interfacing with a Geographical Information System (Black et al. 2002).

References

Bartell, S. M., Campbell, K. R., Best, E. P. H., and Boyd, W. A. (2000). "Interim report for the Upper Mississippi River System - Illinois Waterway System Navigation Study. Ecological risk assessment of the effects of incremental increase of commercial navigation traffic (25, 50, 75, and 100% increase of 1992 baseline traffic) on submerged aquatic plants in the main channel borders," ENV Report 17. U. S. Army Corps of Engineer Districts, Rock Island, St. Louis, St. Paul.

Best, E. P. H., and Boyd, W. A. (1996). "A simulation model for growth of the submersed aquatic macrophyte hydrilla (*Hydrilla verticillata* (L.F.) Royle," Technical Report A-96-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

_____. (1999a). "A simulation model for growth of the submersed aquatic macrophyte Eurasian watermilfoil (*Myriophyllum spicatum* L.)," Technical Report A-99-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

_____. (1999b). "MILFO (Version 1.0): A simulation model for growth of Eurasian watermilfoil – User's guide," Instruction Report A-99-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

_____. (2001a). "A simulation model for growth of the submersed aquatic macrophyte American wildcelery (*Vallisneria americana* Michx.)," ERDC/EL TR-01-5, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

_____. (2001b). "VALLA (Version 1.0): A simulation model for growth of American wildcelery - User's guide," ERDC/EL SR-01-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

_____. (2003). "A simulation model for growth of the submersed aquatic macrophyte sago pondweed (*Potamogeton pectinatus* L.)" (Technical report in preparation), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Best, E. P. H., Jacobs, F. H. H., and Van de Hagen, H. (1987, unpublished). "Biomass characteristics of sago pondweed populations in the Western Canal near Zandvoort, The Netherlands." In: Best, E. P. H., and Boyd, W. A. "A simulation model for *growth of the submersed aquatic macrophyte sago pondweed (Potamogeton pectinatus* L.)," Appendix C (Technical Report in preparation), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Black, P., Best, E. P. H., Newcomb, E. A., Birkenstock, T., Boyt, B., Heath, R., and James, W. F. (2002). "A pilot study of *Vallisneria Americana* changes related to hydraulic modifications to Peoria Lake," (Technical report in preparation).

Boyd, W. A., and Best, E. P. H. (1996). "HYDRIL (Version 1.0): A simulation model for growth of Hydrilla," Instruction Report A-96-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hammer, U. T., and Heseltine, J. M. (1988). "Aquatic macrophytes in saline lakes of the Canadian prairies," *Hydrobiologia* 158, 101-116.

Kantrud, H. A. (1990). "Sago pondweed *(Potamogeton pectinatus* L.*):* A literature review," *U.S. Fish and Wildlife Service, Fish and Wildlife Resource Publication* 176, 89.

Korschgen, C. E. (1989). "Riverine and deepwater habitats for diving ducks." *Habitat management for migrating and wintering waterfowl in North America,* L. M. Smith, R. L. Pederson, and R. M. N. Kaminski, eds., Texas Tech University Press, Lubbock.

Korschgen, C. E., George, L. S., and Green, W. L. (1988). "Feeding ecology of canvasbacks staging on Pool 7 of the Upper Mississippi River," *Waterfowl in winter,* M. W. Weller, ed., University of Minnesota Press, Minneapolis, 237-250.

Pilon, J. (1999). "Progress Report 1998 Netherlands Institute of Ecology," Nieuwersluis, The Netherlands, Royal Dutch Academy of Sciences.

Sahai, R., and Sinha, A. B. (1973). "Productivity of submerged macrophytes in polluted and non-polluted regions of the eutophic Lake Ramgarh (U.P.)." In: C. K. Varshney and J. Rzoska (eds.). Aquatic Weeds in South East Asia. *Proceedings of a Regional Seminar on Noxious Aquatic Vegetation, New Delhi, 12-17 December,* 131-140.

Sher Kaul, S., Oertli, B., Castella, E., and Lachavanne, J. B. (1995). "Relationship between biomass and surface area of six submerged aquatic plant species," *Aquatic Botany* 51, 147-154.

Spencer, D. F., and Anderson, L. W. J. (1987). "Influence of photoperiod on growth, pigment composition and vegetative propagule formation for *Potamogeton nodosus* Poir. and *Potamogeton pectinatus* L," *Aquatic Botany* 28, 102-112.

U.S. Environmental Protection Agency. (1992). *Chesapeake Bay submerged aquatic vegetation habitat requirements and restoration targets: a technical synthesis, Annapolis, Maryland, December 1992*. Printed by the United States Environmental Protection Agency for the Chesapeake Bay Program, contract number 68-WO-0043 15-19.

Van Kraalingen, D. W. G. (1995). "The FSE system for crop simulation," AB-DLO Report. Wageningen, The Netherlands.

Van Kraalingen, D. W. G., Stol, W., Uithol, P. W. J., Verbeek, M. (1991). *User manual of CABO/TPE weather system*. CABO/TPE internal communication, Wageningen, The Netherlands.

Van Wijk, R. J. (1989)."Ecological studies on *Potamogeton pectinatus* L. III. Reproductive strategies and germination ecology," *Aquatic Botany* 33, 271-299.

Westlake, D. F. (1964). "Light extinction, standing crop and photosynthesis within weed beds," *Verhaendlungen internationaler Vereinigung der Limnologie* 15, 415-425.