A TUTORIAL AND TEACHING GUIDE FOR THE USE OF A LOTIC ECOSYSTEM MODEL

by

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PREFACE

The mathematical structures of the three versions of the stream ecosystem model described in this document evolved during a 25-year period. A periphyton model, which later became the Primary Production module of a stream ecosystem model, was programmed in MIMIC while I was on sabbitical leave in 1970-71 at the Center for Quantitative Science, University of Washington (Seattle, WA). The development of Version I of the McIntire and Colby Stream Model was supported mostly by funds from the Western Coniferous Biome, I.B.P., and most of the modeling was done between 1973 and 1976 at Oregon State University. The original mathematical documentation for Version I was prepared by J. A. Colby during the fall of 1976; this documentation was revised by Curtis White in October, 1977, and published as *Internal Report 165: Mathematical Documentation for a Lotic Ecosystem Model* (Coniferous Forest Biome, 1978). The Herbivory and Riparian Versions of the McIntire and Colby Stream Model were based on laboratory and field research conducted at Oregon State University between 1985 and the present. These versions of the model are modifications of Version I and were developed concurrently with an ongoing research program in stream ecology.

Model structure and parameter estimation were based on an enormous amount of information obtained from the literature and directly from an interdisciplinary group of stream ecologists. Among this group, I am particularly indebted to N. H. Anderson, L. R. Ashkenas, R. H. Boling, T. Bott, K. W. Cummins, C. E. Cushing, G. W. Fowler, E. Grafius, S. V. Gregory, J. D. Hall, G. A. Lamberti, G. W. Minshall, J. R. Sedell, A. D. Steinman, W. T. Summer, F. J. Triska, R. L. Vannote, and J. H. Wlosinski for their unselfish willingness to

share ideas and unpublished data. Very special thanks are due W. S. Overton for providing the theory upon which the three versions of the model are based and for his leadership in the development of the various versions of FLEX, a general model processor available at Oregon State University. I am also indebted to Brad Smith for programming the latest version of the FLEX model processor.

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INTRODUCTION

This tutorial provides the conceptual framework, descriptive information, and instructions necessary to run and examine the behavior of three versions of a lotic ecosystem model. Program and data files for these models are stored on the enclosed diskette. To use these files, an IBM or compatible PC with a math coprocessor is required. If the computer is equipped with a hard disk, the user can generate a complete set of output, which in this case, includes a screen display and print files for the simulation runs and the corresponding annual energy budgets. Without a hard disk, it is still possible to obtain the screen display and print files for each run.

The models described below are the McIntire and Colby stream ecosystem model (McIntire and Colby, 1978), henceforth referred to as the M & C Stream Model, and two modified versions of this model that were designed to investigate the process of herbivory and effects of irradiance, food quality, and nutrients on the processes of primary production and grazing. The files required to run these models include the three program files (STREAM.COM, HERB.COM, and RIPARIAN.COM) and a series of files that introduce the input variables; the other files on the diskette (e.g., BUDGET.COM, STRMTAB.COM, STRMTAB.CMD, HERBTAB.COM, HERBTAB.CMD, RIPARTAB.COM, and RIPARTAB.CMD) are required to calculate energy budgets for each simulation run. The three program files represent compiled versions of each model. With each version, the user can change the initial values for the state variables, the parameters, and the input tables (e.g., the irradiance, nutrient, temperature, and flow schedules, as well as the allochthonous introductions). The equations representing functional relationships among the system variables cannot be changed without an alteration of the Pascal procedure files and the generation of a new, compiled version of the model. Files required for this purpose are not included on the diskette. However, a complete mathematical documentation of the three versions of the model is included in the Appendices so the advanced user can reprogram the model with desired modifications in a programming language of choice.

Models and Modeling

From a scientific perspective, modeling is the process of putting structure on knowledge, and a model is some kind of statement of relationships. Therefore, all research scientists are modelers in the sense that they are involved in generating and updating conceptual models that evolve from field and laboratory studies. In some cases, it is useful to transform conceptual models into integrated numerical systems by mathematical formalization. In ecology, mathematical modeling is the translation of an ecological system into mathematical form and the subsequent investigation of the mathematical system, usually by computer simulation.

Overall goals of model building are description and prediction. In particular, mathematical models can be used for simple forecasting (e.g., the weather) or for scientific purposes: (1) for hypothesis generation; (2) to synthesize the results of field and laboratory studies; (3) to evaluate a data base; and (4) to set priorities for future research. The process of model building usually includes the selection and classification of variables, equation writing and parameterization, simulation, and the comparison of model output with the behavior of the natural system under consideration (model testing). In this tutorial, we discuss the use of mathematical modeling for the scientific investigation of biological processes in lotic ecosystems.

The Role of Modeling in Stream Ecology

Lotic ecosystems have been investigated from the trophic level viewpoint (Odum, 1957; Warren et al., 1964) and more recently within the conceptual framework of functional groups (Cummins, 1974; Boling et al., 1975) or relevant dynamic processes (McIntire, 1983). The functional group approach involves the classification of taxonomic entities into groups of organisms considered to be similar to each other with respect to trophic position and function. Historically, the corresponding approach to analysis has been concerned with state variable dynamics, in this case with the biomass or numerical abundance of organisms in each functional group. In contrast, the process viewpoint is less concerned with taxonomic categories and places more emphasis on the capacity of a system or subsystem to process inputs. The stream models described in the following sections of this document are compatible with both the functional group and process viewpoints.

Functional groups of stream organisms do not live in isolation. Individual taxa experience complex interactions with abiotic and biotic components within the functional unit, and the group as a whole changes its structural and functional attributes in response to direct and indirect relationships with components outside the boundaries of the group. In the field or laboratory, experiments with functional groups of stream organisms are usually designed to examine effects of only one or at most, a few variables in systems that maintain the same environment with respect to the variables not under investigation. The role of modeling, as conceptualized in this tutorial, is to provide a context and coupling structure for the experimental work that will help optimize the relevancy of a particular experiment to the objective questions under consideration.

One approach to the study and modeling of lotic ecosystems includes: (1) identification of research goals and a set of corresponding specific objectives; (2) an initial system conceptualization, a process that involves the definition of system variables and their couplings, and the determination of appropriate levels of resolution relative to time and space; (3) translation of biological concepts into mathematical form and subsequent investigation of the mathematical model in relation to the objective questions under consideration; (4) validation of model behavior by the collection of observational data in the field; (5) generation of new hypotheses that are based on priorities revealed by modeling and field observations; (6) design and performance of experiments to examine new hypotheses; (7) modification of the mathematical model and system conceptualization based on the latest field observations and experimental results; and (8) reevaluation of specific objectives and research progress in relation to the level of understanding generated by the most recent round of experimental work and modeling. In summary, this approach is iterative and synthetic, and involves the careful interplay between modeling, field observation, experimentation, and a periodic update of specific objectives in relation to an overall research goal.

THE M&C STREAM MODEL: VERSION I

The structure and mathematical details of the M & C Stream Model were described by McIntire and Colby (1978). Model structure was based on the process point of view (McIntire, 1983) and current concepts of functional groups in stream ecology (McIntire, 1968, 1973; Cummins, 1974). In this case, ecosystems were conceptualized as hierarchical systems of biological processes with physical and chemical processes expressed as driving or control variables. Depending on the resolution levels of interest, various biological processes were the systems, subsystems, and suprasystems under consideration. This view of ecological systems is consistent with FLEX, a general ecosystem model paradigm developed by Overton (1972, 1975) and based on the general systems theory of Klir (1969). The original version of the model was developed for scientific purposes: to generate hypotheses, to synthesize the results of field and laboratory research, to evaluate a data base, and to set priorities for future research. More recently the model has been used for teaching purposes and for the generation of new hypotheses related to the processes of primary production and grazing in lotic ecosystems.

Briefly, the M & C Stream Model has a hierarchical structure and represents biological processes that are usually active in most lotic ecosystems. From this perspective, stream ecosystems are conceptualized as two coupled subsystems, the processes of primary consumption and predation (Fig. 1). Primary Consumption represents all processes associated with the direct consumption and decomposition of both autotrophic organisms and detritus, including the autochthonous production dynamics of the autotrophic organisms collectively. Predation includes processes related to the transfer of energy among primary, secondary, and tertiary macroconsumers. The subsystems of Predation are the processes of invertebrate and vertebrate predation, whereas Primary Consumption is represented by the processes of herbivory and detrtivory. Herbivory consists of all processes associated with the production and consumption of autotrophic organisms within the system, whereas Detritivory includes the consumption and decomposition of detrital inputs. The corresponding subsystems of

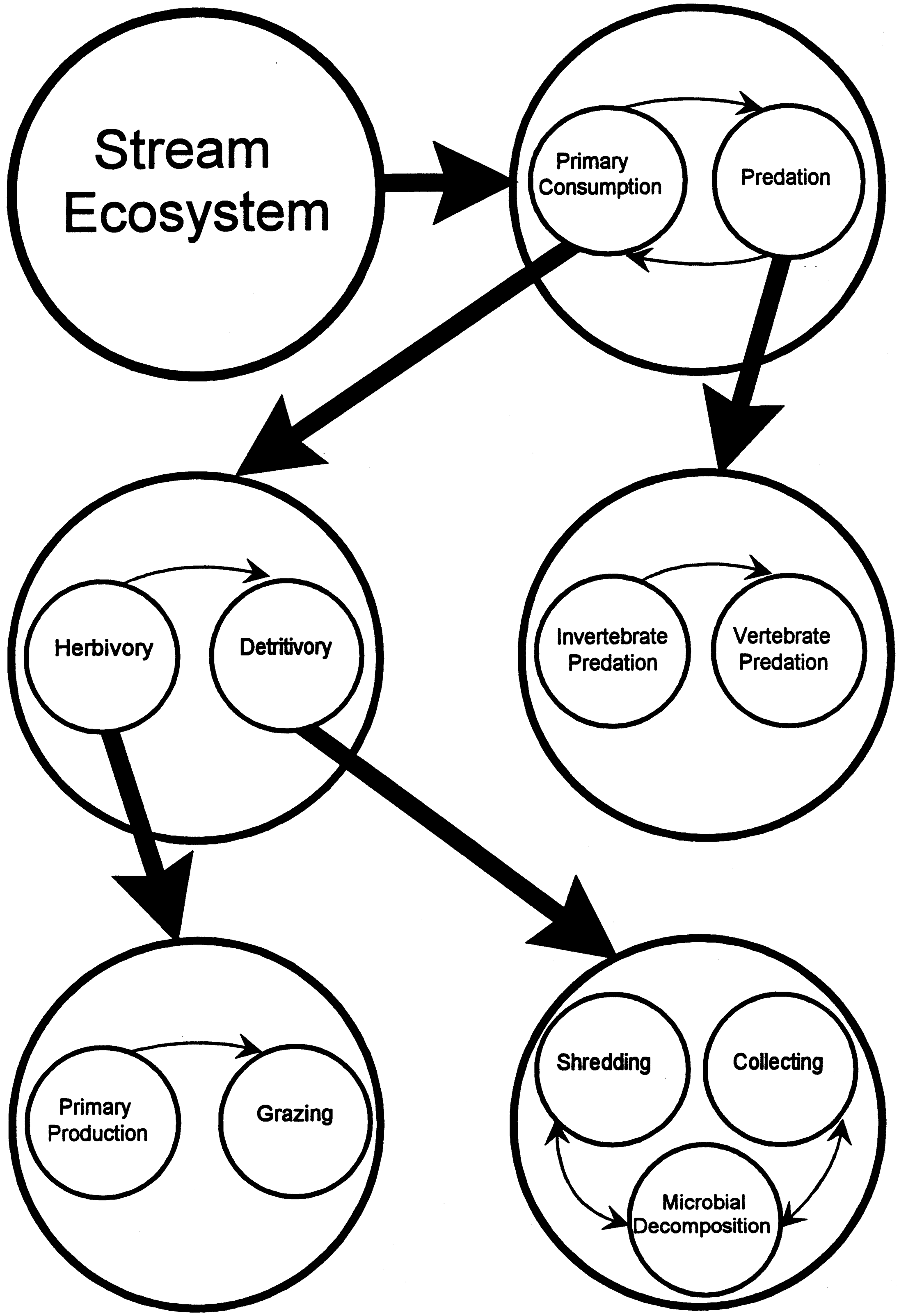


Figure 1. Schematic representation of a lotic ecosystem showing the hierarchical decomposition of the Primary Consumption and Predation subsystems. Arrows within processes indicate patterns of energy flow.

Herbivory are Primary Production and Grazing, and those of Detritivory include Shredding, Collecting, and Microbial Decomposition (Fig. 1).

The M & C Stream Model is programmed in Pascal as a series of procedure files that were cocompiled with FLEXPC.COM, a model processor that is compatible with the FLEX paradigm. Instructions for running Version I of the model include a short introduction to the Standard Run and the more detailed, step by step, procedure for producing various kinds of output from the Standard Run. In addition, the procedures for modifying the Standard Run are outlined. Such modifications can be introduced by changing the input tables, parameters, and initial conditions. A complete mathematical documentation of Version I of the M & C Stream Model is presented in Appendix I (page 146).

The Standard Run for Version I

The Standard Run for Version I of the M & C Stream Model simulates the process dynamics of a small, low-order stream that is shaded in the summer by a dense canopy of riparian vegetation and receives annual allochthonous organic inputs of 473 g m^{-2}. If the input tables are not changed, this run generates the state variable trajectories illustrated by McIntire and Colby (1978, Fig. 4). This version of the model has 11 state variables that represent biomasses associated with the processes of grazing ($\mathbf{x_2}$), shredding ($\mathbf{x_3}$), collecting ($\mathbf{x_4}$), vertebrate predation ($\mathbf{x_5}$), invertebrate predation ($\mathbf{x_6}$), and primary production ($\mathbf{x_7}$); and biomasses associated with the decomposition of fine particulate organic matter ($\mathbf{x_8}$) and four categories of large particulate organic matter ($\mathbf{x_9}$, $\mathbf{x_{10}}$, $\mathbf{x_{11}}$, and $\mathbf{x_{12}}$). In addition, two other state variables ($\mathbf{x_{13}}$ and $\mathbf{x_{14}}$) are used as dummy variables to introduce lag times for the microbial conditioning of the allochthonous organic inputs. The variable $\mathbf{x_1}$ is not used in Version I of the model.

The files that introduce the input variables for the Standard Run are:

File	Variable
EXLITE	daily mean illumination expressed as ft-c;
XNUTR	limiting nutrient concentration (mg l^{-1}), NO_3^- in this case;
STRFLOW	stream flow (cfs);
SALLOC	slow-conditioned allochthonous daily input (g m^{-2});
FALLOC	fast-conditioned allochthonous daily input (g m^{-2});
GEMER	daily emergence losses (g m^{-2}) for grazers;
SEMER	daily emergence losses (g m^{-2}) for shredders;
CEMER	daily emergence losses (g m^{-2}) for collectors;
PEMER	daily emergence losses (g m^{-2}) for invertebrate predators;
STRTEMP	daily mean water temperature (°C);
PHOTPER	number of daylight hours per day (hr day^{-1}).

Each file consists of a table of 360 values representing the daily inputs for a one-year simulation run based on 12 30-day months. Schedules of illumination and allochthonous inputs (Appendix II) were obtained from direct measurements at sites on Berry Creek, a small stream near Corvallis, Oregon, and Watershed 10, a research area at the H. J. Andrews Experimental Forest, approximately 60 mi east of Eugene, Oregon. Patterns of these inputs are illustrated in Figures 2A and 2B, whereas hydrologic properties generated by the stream flow schedule (**STRFLOW**) are tabulated in Table 1. For more detail, the user can plot the values in each table and examine listings of the tables in Appendix II..

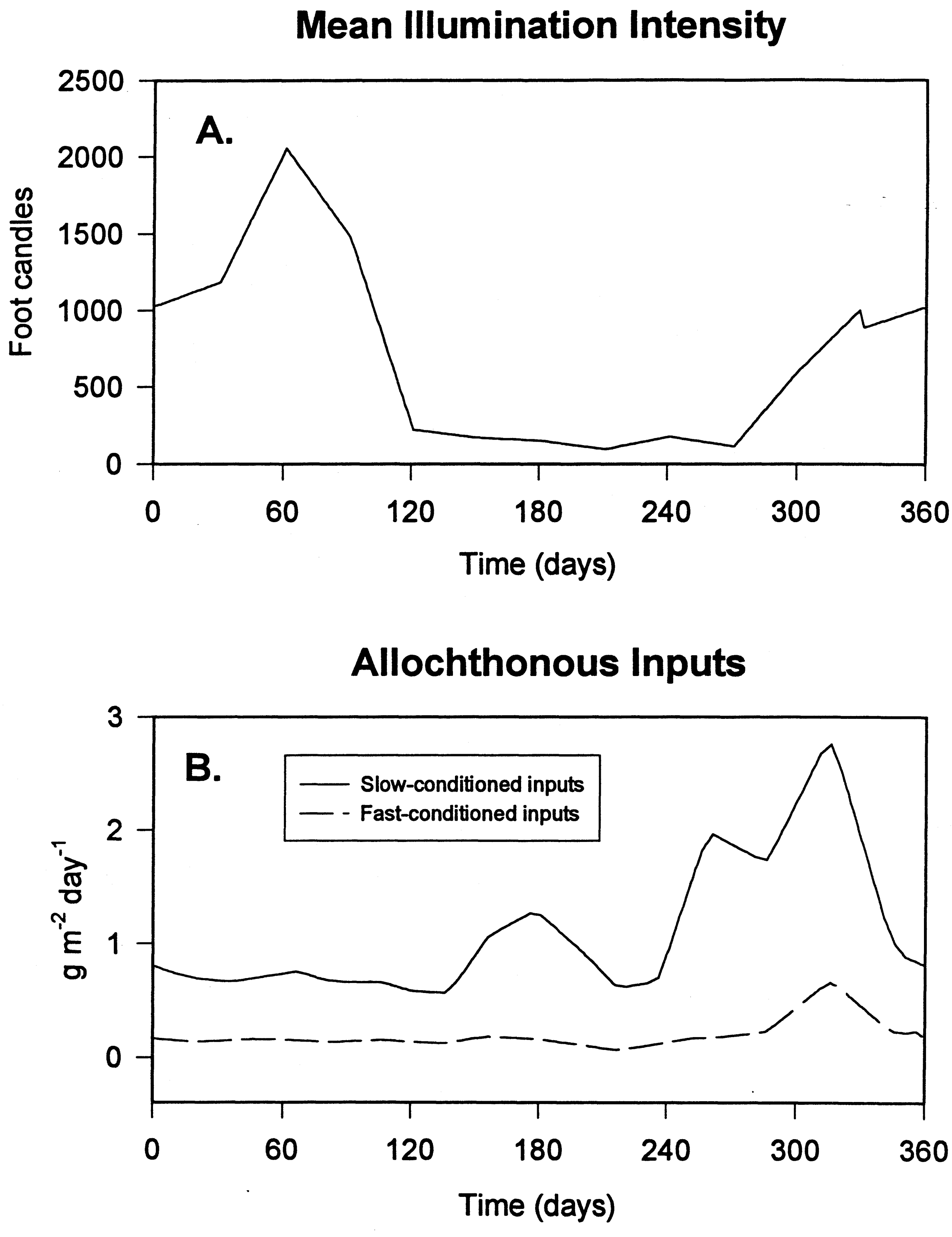


Figure 2. Schedules of illumination (A) and allochthonous inputs (B) for the Standard Run of Version I of the M & C Stream Model. Data were obtained from Berry Creek and Watershed 10 (see text).

Table 1. Hydrologic properties associated with the Standard Run of Version I of the M & C Stream Model. Maximum, minimum, and mean values correspond to output from a 1-year simulation run at a time resolution of one day. Parameters for the equations and the mean channel slope are based on data for Oak Creek, near Corvallis, Oregon.

Property	Units	Maximum	Minimum	Mean
Flow	cm s^{-1}	3540	22	221
Current Velocity	cm s^{-1}	231	20	50
Suspended Load	mg l^{-1}	330	1	14
Roughness Coefficient	none	0.075	0.048	0.054
Channel Width	m	3.17	3.12	3.13
Channel Depth	m	0.58	0.03	0.09
Cross-sectional Area	m^2	6.95	0.28	0.94
Channel slope	%	-	-	1.4

Simulation Procedures

This section describes the procedures for (1) generating output from the Standard Run; (2) changing the screen output display; (3) changing parameter values; (4) creating files for printing or plotting; and (5) generating an annual energy budget. The commands that the user must supply are indicated in bold type.

If your computer has a hard disk (assumed here to be the C drive), type

C:\>**md model** (return)

C:\>**cd model** (return)

C:\MODEL>**md stand** (return)

C:\MODEL>**cd stand** (return)

C:\MODEL\STAND>**copy a:\stand*.*** (return)

C:\MODEL\STAND > **dir** (return)

This set of commands assumes that you have placed the diskette containing the files for the M & C Stream Model in the A drive. The commands create a new directory and subdirectory on the C drive named MODEL and MODEL\STAND, and copies all of the files stored on the STAND subdirectory of the diskette from the A drive to C:\MODEL\STAND. The **dir** command provides a listing of all files that were transferred from the A drive.

To run the model, type

C:\MODEL\STAND > **stream** (return)

This command calls up the compiled version of the M & C Stream Model and puts the user in communication with the FLEX model processor. After the CMD > prompt is displayed on the screen, type

CMD > **read=stream.cmd** (return)

This command introduces a file that specifies the parameters, input tables, initial values for the state variables, run length, and output instructions for a particular run. The user also has the option of supplying or changing this information directly from the keyboard. However, for a relatively large model, the best strategy is to read in a command file, STREAM.CMD in this case, and then make any necessary modifications directly from the keyboard. This procedure is illustrated by some examples below. To generate screen output for a one-year simulation, type

CMD > **run** (return)

With this command, the model processor will display the values for six state variables ($\mathbf{x_2}$, $\mathbf{x_3}$, $\mathbf{x_4}$, $\mathbf{x_5}$, $\mathbf{x_6}$, and $\mathbf{x_7}$) at a monthly time resolution (i.e., for days 30, 60, 90, ..., 330, and

360). The time interval and variables displayed on the screen were specified in the command file (STREAM.CMD). They can be changed by changing the commands in this file or by the appropriate commands from the keyboard. For example, press the return key to get back into the command mode and type

CMD>**reset** (return)

The reset command sets the time step back to zero which allows for the initiation of a new run. Next, type

CMD>**sint=5** (return)

CMD>**sset=x(9)** (return)

CMD>**skill=x(6)** (return)

CMD>**slist** (return)

The first command (**sint=5**) sets the screen display to a 5-day interval and overrides the 30-day interval set in the command file. The **sset** command adds a new state variable ($\mathbf{x_9}$) to the screen display, while the **skill** command omits a state variable ($\mathbf{x_6}$) from the screen display. The user can check the variables that will be displayed on the screen at any time by typing **slist**. To make a run with the updated output requirements, simply type

CMD>**run** (return)

After this run is completed, press the return key and enter the **reset** command. For the next run, type

CMD>**ib(92)=.7** (return)

This entry introduces a new command (**ib(??)=?**) that provides the user with the opportunity to change the parameter values. In this case, the parameter $\mathbf{b_{92}}$ has been changed from its original value of 0.55 to a new value of 0.7. The original value was introduced by the command file (STREAM.CMD). In the M & C Stream Model, the assimilation associated with the process of grazing is calculated by multiplying the food consumption by $\mathbf{b_{92}}$, the assimilation efficiency parameter. At this point, the user can again run the model for a one-year simulation while using the original initial values for the state variables, or the model can be run for a longer period to determine a new set of initial conditions that will generate steady state dynamics for the new $\mathbf{b_{92}}$ value. For an example of the latter option, type

CMD>**tstop=5400** (return)

CMD>**sint=360** (return)

CMD>**sset=(6,8,10:14)** (return)

CMD>**slist** (return)

The **tstop** command changes the run length from 1 year (360 days), the value set by the command file, to 15 years (5400 days). For this run, it is also necessary to output all state variables (x_2 - x_{14}), and desirable to change the screen output interval to 1 year (360 days). The **sset** command adds $\mathbf{x_6}$, $\mathbf{x_8}$, $\mathbf{x_{10}}$, $\mathbf{x_{11}}$, $\mathbf{x_{12}}$, $\mathbf{x_{13}}$, and $\mathbf{x_{14}}$ to the list of state variables for screen output. Initiate the simulation by

CMD>**run** (return)

Watch the 13 state variable values as they gradually change during the long-term simulation. Because of the yearly output resolution, each set of 13 values represents the vector of state variables at the beginning of each year. As soon as the vector has converged to a constant set of values, in this case by day 5040 (after 14 years), the steady state initial values for the state variables are established for the new set of parameters or input variables. Copy down these values or print the information on the screen, press the return key, and type

CMD > **reset** (return)

CMD > **tstop=360** (return)

CMD > **ix(2:8)=1.64,1.307,2.848,3.931,.114,.841,8.016** (return)

CMD > **ix(9:14)=123.917,24.691,30.851,1.145,16.978,.668** (return)

The first two commands reset the system and change the run length back to one year. The **ix(??)=?** commands introduce the new steady state initial values for the state variables. In other words, the system should return to these values on the last day of each year if they are correct. Check this out with the command

CMD > **run** (return)

(Note: In this case, a slight discrepency in x_5, x_8, and x_9 is caused by a rounding error.)

The next example generates a separate file of output that can be sent to a printing device or reproduced on the screen by the DOS **type** command. Press the return key and type

CMD > **reset** (return)

CMD > **skill=x(8,10:14)** (return)

CMD > **sint=10** (return)

CMD > **slist** (return)

CMD > **pfile=leroy.out** (return)

CMD > **pint=30** (return)

CMD > **pset=x(2:7,9)** (return)

CMD > **plist** (return)

The first four commands reset the system and change the screen output to state variables x_2 -

x_7 and an output interval of 10 days. The **pfile** command sets up a print file. The user also can specify another disk drive or directory for the storage of this file (e.g., **pfile=b:leroy.out**). The **pint**, **pset**, and **plist** commands are analogous to the corresponding screen commands and specify the output interval and the desired output variables (x_2 - x_7 and x_9 in this case). Type

CMD>**run** (return)

Press the return key and type

CMD>**q** (return)

The **q** or **quit** command transfers the user back to DOS. Hard copy of the last run can be obtained by sending the print file LEROY.OUT to an appropriate printing device. This file includes a list of all parameter values, initial values for the state variables, initial values for a set of memory variables, a list of input tables, and values for the output variables at a time resolution specified by the **pint=** command (Appendix III). If the user wishes to plot the output variables against each other or against a temporal scale, the **d???** series commands allow for the creation of a dump file that provides a convenient table of these values without the supporting information included in the print file (i.e., the list of parameters and initial conditions). To create an example of a dump file for the Standard Run, type

C:\MODEL\STAND>**stream** (return)

CMD>**read=stream.cmd** (return)

CMD>**dfile=c:\model\stand\leon.out** (return)

CMD>**dint=1** (return)

CMD>**dset=x(2:7)** (return)

CMD>**delim=,** (return)

CMD>**run** (return)

After the end of the run, press the (return) key and type

CMD>**q** (return)

The **dfile** command specifies the name and drive\directory for the dump file. Since dump files often are relatively large, it may be necessary to store the file on a different diskette or on a particular subdirectory of a hard disk (if available). In the above example, the dump file LEON.OUT requires 5404 bytes and is stored on the C drive in the directory MODEL and subdirectory STAND. The **dint** and **dset** commands specify the output interval and variables, respectively, and are analogous to the corresponding **s???** and **p???** commands introduced earlier. Some plotting and spreadsheet programs require a delimiter between the data entries before the file can be read in for analysis. If this is the case, the user can insert the delimiter of choice, a comma in this example, by using the **delim** command. If a delimiter is not entered, a space will separate each value in the file. The user can examine the structure of the dump file by getting a listing on the screen using the DOS command

C:\MODEL\STAND>**type leon.out** (return)

or, the file can be modified in the DOS editor (or in any other editor). For example, type

C:\MODEL\STAND>**edit leon.out** (return)

Structure of the Command File

As indicated on page 11, the command file allows the user to introduce all of the information that is necessary to initiate a particular simulation run. If the model is relatively large and the user intends to make a number of runs, the command file provides the user with a way to introduce most of the necessary information without having to retype it for each individual run. Minor modifications to this file then can be made before each run in the command or CMD > mode of the FLEX model processor as illustrated in the examples presented above.

The structure of the command file (STREAM.CMD) used in the examples is:

```
line 1:   LEVEL=1
line 2:   IB(1:10)=0,1.39E-2,5.7E-2,-1,0,0.114,0.581,1.97E-4,-94.4,9.42E3
line 3:   IB(11:20)=1.08E3,4.88E-2,8.83E-2,10.2,2.95E-3,1.07,0.633,1.1,1.6E2,1.5
line 4:   IB(21:30)=4,0.8,1,4,0.5,0,0,3.5,3.5,0
line 5:   IB(31:40)=9.95E-2,0.465,0.895,0.56,1.9,1.51,0.294,2.03,1.28E-4,1.28E-4
line 6:   IB(41:50)=1.38E-3,1.38E-3,-1,0,0.187,2.33E-3,1.74E-2,0,0,0.3
line 7:   IB(51:60)=0.86,0.1,1.87E-3,2.5E-3,2.6E-2,1.88E-2,0.42,0.82,0.05,100
line 8:   IB(61:70)=0,0,0,3,0.01,2.8E-2,0.583,1.0E-3,0.5,1.92E-2
line 9:   IB(71:80)=2.1E-3,0.7,0,7.4E-3,1.08E-3,0.1,0.4,2.68E2,2.95,0.187
line 10:  IB(81:90)=1.46E-2,2.96E-2,1.46E-2,15,0.8,12,0.35,0.7,0.237,1.0E3
line 11:  IB(91:100)=2.4E3,0.55,0.18,0.21,0,0.3,0.3,0.3,0.167,1
line 12:  IB(101:107)=4.46E-3,4.46E-3,4.46E-3,-1,1.44E-4,0,5.85E-2
line 13:  IB(108:114)=9.11E-4,1.99E-4,5.85E-2,-1,-1,-1,-1
line 14:  IX(1:11)=0,1.415,1.305,3.075,3.974,0.112,0.932,8.228,123.962,24.7,30.851
line 15:  IX(12:14)=1.145,16.978,0.668
line 16:  IM(2:7)=0.0,0.0,0.0,0.0,0.0,0.0
line 17:  TARGET
line 18:  SSET=X(2:7)
line 19:  SINT=30
line 20:  SLIST
line 21:  TSTOP=360
line 22:  TABLE(1)=EXLITE
line 23:  TABLE(2)=XNUTR
line 24:  TABLE(3)=STRFLOW
line 25:  TABLE(4)=SALLOC
line 26:  TABLE(5)=FALLOC
line 27:  TABLE(6)=GEMER
line 28:  TABLE(7)=SEMER
line 29:  TABLE(8)=CEMER
line 30:  TABLE(9)=PEMER
line 31:  TABLE(10)=STRTEMP
line 32:  TABLE(11)=PHOTPER
```

The **LEVEL=1** command indicates that the model will run at one time resolution, in this case at a time period of one day. In a later section, a two level model is described (RIPARIAN.COM) in which part of the system runs at an hourly time resolution, whereas the rest of the system is updated at a daily resolution. The **IB(?:?)** commands (lines 2 - 13) introduce the initial set of parameters. In this version of the model (STREAM.COM), there are 114 parameters (see APPENDIX I for details). The **IX(?:?)** and **IM(?:?)** commands (lines 14 - 16) specify initial values for state variables and memory variables, respectively. If the system is in a steady state, the state variables return to their initial values, usually on an annual cycle if input tables are structured on an annual cycle. However, in some cases, cycles can assume a 2, 3, 4, or as long as a 12-year time period because of lag time effects with certain combinations of parameters and inputs. Memory variables are past values of system inputs or state variables. The **TARGET** command (line 17) simply indicates the desired level for the print file, dump file, and screen output. The location of this command is important when the model has more than one level. The **TSTOP=** command (line 21) sets the length of the simulation run, 360 days in this example, whereas the **S???** commands (lines 18 - 20) are explained in the previous section.

Lines 22 - 32 in the command file specify the input tables. This version of the model requires 11 tables of inputs that represent illumination intensity (Table 1); nutrients (Table 2); stream flow (Table 3); allochthonous inputs of organic matter (Tables 4 and 5); emergence losses associated with grazers, shredders, collectors, and invertebrate predators (Tables 6, 7, 8, and 9); stream temperature (Table 10); and the number of daylight hours per day (Table 11). The structure of these tables is explained in the next section. The user can designate any name for each of these tables as long as the table numbers correspond to the variables indicated above.

Manipulations of Input Files and Parameters

This section suggests some additional manipulations that will allow the user to become more familiar with the kind of output that the model can generate. Such manipulations fall into three categories: (1) changes in the input tables; (2) changes in the parameters; and (3) changes in the initial values for the state variables.

As indicated in the previous section, STREAM.COM requires 11 input tables, each of which can be altered when a different schedule of inputs is desired. Each table consists of 360 values, one for each day of the year, and is read a row at a time from left to right. The format of these tables can be variable; a space between each value is all that is required. For example, to examine the schedule of illumination inputs, type

C:\MODEL\STAND>**type exlite** (return)

The corresponding listing on the screen represents a table of 360 daily average values for illumination intensity expressed as foot-candles, the unit that was used in the first version of the model. The irradiation equivalent (μmol quanta m^{-2} s^{-1}) for these values is roughly 0.2 times each entry, i.e., 20% of each value. In the PASCAL code, the tables are identified by numbers, and the command file (STREAM.CMD) equates each number to the appropriate input file name. For example, a new table of irradiation inputs (NEWNAME) can be introduced by changing line 26 of the command file from TABLE (1)=EXLITE to TABLE(1)=NEWNAME.

The standard version of the M & C Stream Model (STREAM.COM) is particularly suitable for simulating effects of various combinations of irradiance and allochthonous inputs. To examine these variables, the user can change the light schedule (EXLITE) as indicated above, and the two tables of allochthonous inputs (SALLOC and FALLOC). In this case, SALLOC simulates the introduction of organic matter, expressed as g m^{-2} day^{-1}, that undergoes microbial conditioning slowly (130-day lag time), and FALLOC is the input table that represents material that is conditioned more rapidly (30-day lag time). The total input from these two tables is 473 g m^{-2} yr^{-1}.

Changes in parameters are introduced in command mode (CMD>) before a run by the **ib(?)=?** command as described on page 12 or by changing values in the command file before calling up the model processor. A complete list of parameters and their definitions for the Version I of the model (STREAM.COM) are presented in Section 6 of APPENDIX I. Some interesting parameters that the user can change without reference to Section 6 or the complete model documentation (APPENDIX I) are:

Parameter	Standard Value	Explanation
b_{92}	0.55	grazer assimilation ratio
b_{93}	0.18	shredder assimilation ratio
b_{94}	0.21	collector assimilation ratio
b_{58}	0.82	invertebrate predator assimilation ratio
b_{51}	0.86	vertebrate predator assimilation ratio
b_{72}	0.7 g m^{-2}	algal refuge parameter
b_{96}	0.3 g m^{-2}	grazer refuge parameter
b_{97}	0.3 g m^{-2}	shredder refuge parameter
b_{98}	0.3 g m^{-2}	collector refuge parameter

b_4	-1	constant temperature
b_{113}	-1	constant irradiance
b_{111}	-1	constant NO_3 (nutrient) concentration
b_{114}	-1	constant allochthonous input (slow lag time)
b_{104}	-1	constant allochthonous input (fast lag time)

The parameters b_{92}, b_{93}, b_{94}, b_{58}, and b_{51} establish the assimilation ratios for the major consumer processes. In the model, assimilation for each process is calculated by multiplying food consumption by the appropriate ratio. Past research indicates that model behavior is relatively sensitive to these parameters.

The refuge parameters (b_{72}, b_{96}, b_{97}, and b_{98}) set a resource biomass to its lower limit of availability. In other words, if b_{72} is set at 0.7 g m^{-2}, the algal biomass available to the process of grazing at any particular time is x_7 - 0.7 g m^{-2}, where x_7 is the total algal biomass at that time. The other parameters set refuge levels for grazers, shredders, and collectors in relation to exploitation by the processes of vertebrate and invertebrate predation.

The parameters b_4, b_{113}, b_{111}, b_{114}, and b_{104} provide the user with the option of introducing a constant value for the corresponding input variables. When these values are negative (e.g., -1), the processor will read the input tables. Alternatively, if they are set to a value of zero or greater, the processor will ignore the table and read the input as a constant value equal to the parameter.

Another interesting manipulation of the model inputs can be investigated by changing the initial values for the state variables. In particular, it is informative to investigate model behavior in the absence of various processes. For this kind of analysis, simply set the initial state variable value to zero, an input that is accomplished by typing

CMD > **ix( )=0** (return)

with the state variable of interest indicated between the parentheses. In this way, it is possible, for example, to examine the dynamics of grazing, shredding, and collecting in the presence and absence of predation; or investigate system dynamics with or without the process of grazing.

The Energy Budget

The enclosed diskette also contains three files (STRMTAB.COM, STRMTAB.CMD, and BUDGET.COM) that allow the user to obtain an annual energy budget for any set of inputs, parameters, or initial conditions. STRMTAB.COM generates the same system dynamics as STREAM.COM, while calculating the additional variables necessary for the energy budget. If an energy budget is not desired, STREAM.COM should be used instead of STRMTAB.COM, as the run time associated with the latter program is approximately three times longer than the corresponding time for STREAM.COM.

The command file for STRMTAB.COM is STRMTAB.CMD. This file contains the same information as STREAM.CMD, and in addition, sets up a dump file that contains 360 values for each of the 55 variables required for the energy budget. STRMTAB.CMD instructs the model processor to set up a dump file named STREAM.DMP, and then stores this file on the current disk drive and directory/subdirectory, C:\MODEL\STAND in the example discussed above. (STREAM.DMP for the Standard Run occupies 469912 bytes of memory and is too large for the standard 5-inch floppy disk.) The dump file destination can be changed by an appropriate modification of the **dfile=** command in STRMTAB.CMD.

BUDGET.COM reads the dump file (STREAM.DMP) and synthesizes this information into three tables which summarize the bioenergetics of the system at an annual time resolution (360 days). The output file from BUDGET.COM is named STREAM.TAB, a file that can be listed on the screen or sent to a printing device if hard copy is desired.

To generate an energy budget for the Standard Run, type

C:\MODEL\STAND > **strmtab** (return)

CMD > **read=strmtab.cmd** (return)

CMD > **run** (return)

After the simulation is complete, press the return key and type

CMD > **q** (return)

C:\MODEL\STAND > **budget** (return)

After these commands, the program will print "Please enter the simulation run number" on the screen. The user then can identify the run by a number or a series of words. For example, type

(space) **Run Number 1** (return)

After execution, the program will print "End of Pascal execution" on the screen. At this point, the output file (STREAM.TAB) is stored on C:\MODEL\STAND and can be printed or examined on the screen. Type

C:\MODEL\STAND > **type stream.tab** (return)

or

C:\MODEL\STAND > **print stream.tab** (return)

The output that you will get from your printer is listed in Appendix IV.

Energy budgets can be obtained for any combination of inputs, parameters, or initial conditions. The recommended procedure for generating output from the M & C Stream Model is summarized in the following steps:

1. Use STREAM.COM and STREAM.CMD to explore a set of changes in parameters, initial conditions, or inputs;

2. After the particular set of runs of interest are identified, determine the steady state initial conditions that are compatible with the desired changes for each run (follow the procedure outlined on pages 12 -14);

3. If an energy budget is not desired, use STREAM.COM and STREAM.CMD to generate one-year steady state simulations with print files and dump files (if plots are needed);

4. If an energy budget is required, use STRMTAB.COM and STRMTAB.CMD to generate one-year steady state runs with print files and an energy budget.

An example of step 4 for the case discussed in the Simulation Procedures section can be examined by typing

C:\MODEL\STAND>**strmtab**	(return)
CMD>**read=strmtab.cmd**	(return)
CMD>**ib(92)=.7**	(return)
CMD>**ix(2:8)=1.64,1.307,2.848,3.931,.114,.841,8.016**	(return)
CMD>**ix(9:14)=123.917,24.691,30.851,1.145,16.978,.668**	(return)
CMD>**pfile=leon.out**	(return)
CMD>**pint=10**	(return)
CMD>**pset=x(2:7)**	(return)

CMD > **run** (return)

After the run is complete, press the return key and type

CMD > **q** (return)

C:\MODEL\STAND > **budget** (return)

(space) **Run Number 2** (return)

After execution of BUDGET.COM, type

C:\MODEL\STAND > **print leon.out** (return)

C:\MODEL\STAND > **print stream.tab** (return)

Description of Energy Budget Tables

The file STREAM.TAB contains three tables that summarize the energy relations among the biological processes represented by the M & C Stream Model. Table 1 (Appendix IV, page 209) provides the annual (360-day) mean biomass for functional groups of organisms representing the processes of grazing, shredding, collecting, vertebrate predation, invertebrate predation, and primary production (i.e., the state variables x_2, x_3, x_4, x_5, x_6, and x_7, respectively). In addition, corresponding standard deviations, maximum, and minimum values also are tabulated for the 360-day period. Other information for each process includes the annual production and assimilation, turnover times per year, and the various fates of the assimilated energy. Table 2 (Appendix IV, page 210) represents the bioenergetics of the detrital processes. Here, annual mean biomasses, standard deviations, maximum, and minimum values are tabulated for fine particulate organic matter (FPOM) and large particulate organic matter (LPOM). LPOM is partitioned into a conditioned fraction, with a slow and fast time resolution (SLPOM and FLPOM), and the unconditioned material with the same compartments. For more information about this aspect of the model structure, see page 170 of McIntire and Colby (1978). Table 2 also indicates the sources of FPOM and LPOM and the fates of corresponding inputs. Table 3 (Appendix IV, page 210) provides an energy budget for the whole ecosystem. The total inputs, which consist of gross primary production and allocthonous material from the terrestrial environment, are listed in the column on the left, whereas the losses of energy are tabulated in the column on the right. If the system is operating with steady state initial conditions, the inputs and losses should be equal, plus or minus a small rounding error. The ratio GPP/CR indicates whether the system as a whole is autotrophic or heterotrophic.

Some Useful Output Variables

Concepts

The dynamics of biological processes in ecosystems can be examined relative to (1) the potential to expand process capacity, (2) process production, (3) the realized growth of process capacity, and (4) process regulation (McIntire, 1983). Theoretically, process capacity includes two components -- a quantitative aspect which is the biomass at any instant of time involved in the process, and a qualitative aspect which relates to taxonomic composition and physiological state. In the M & C Stream model, qualitative changes within a process are not represented, and state variables are defined as the biomasses associated with the various processes. In particular, the model emphasizes the responses of the processes of primary production, grazing, shredding, collecting, invertebrate predation, vertebrate predation, and detrital decomposition to inputs of energy, namely solar radiation and allochthonous detritus. Therefore, simulation output requested by the **pfile** and **dfile** commands usually include values for state variables (i.e., the biomasses) that can be plotted as temporal trajectories (see Fig. 3) or against each other as a phase diagram.

In studies of natural ecosystems, it is often difficult to understand mechanisms that account for system dynamics from plots of state variables. In other words, values for state variables go up and down, but it is not always intuitively obvious why such variations occur. Likewise, state variable dynamics in ecosystem models also can be difficult to interpret, which may seem surprising considering that the model is the investigator's own creation. As a result, we frequently find ourselves in the frustrating situation of not even being able to understand the behavior of our simple models, let alone the real world itself. To help with the problem of model interpretation, McIntire and Colby (1978) and McIntire (1983) introduced a set of variables that can be used to identify mechanisms that control or regulate changes in state variable values during each simulation run. These variables are based on the four concepts introduced in the preceding paragraph.

The potential to expand the biomass associated with a consumer process (e.g., grazing, shredding, and collecting) at time k is given by

$$r_{potential}(k)_i = \frac{a_i D_i(k) - C_i(k)}{x_i(k)} , \qquad (1)$$

where

$x_i(k)$ = the biomass of process *i* at time k,

$D_i(k)$ = the demand for food for process *i* at time k,

$C_i(k)$ = the cost of processing for process *i* at time k,

a_i = an efficiency parameter for process *i*.

Process demand (*D*) represents resource consumption by a consumer process when resources

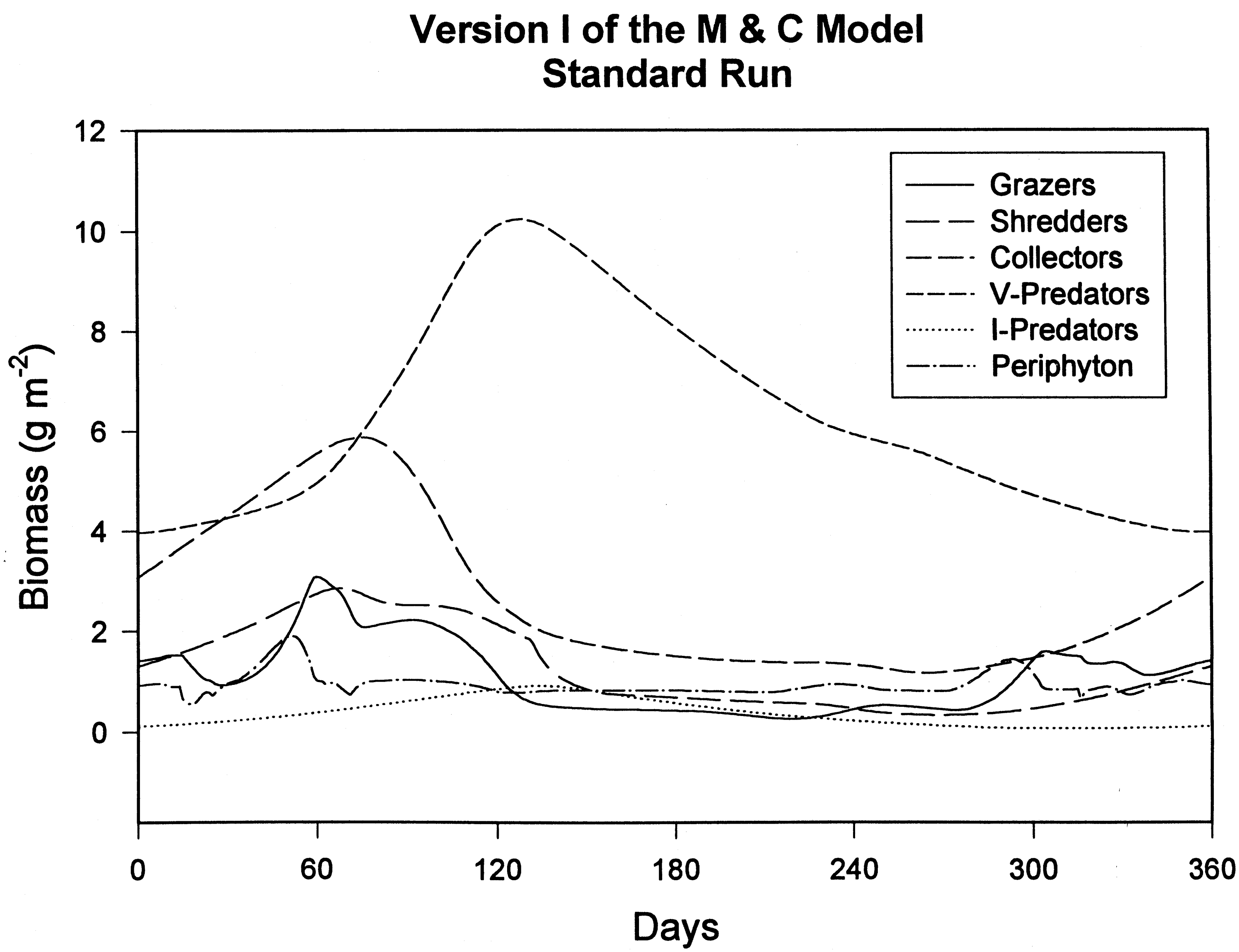


Figure 3. Steady state, seasonal dynamics of state variables representing the major biological processes in Version I of the McIntire and Colby Stream Model. The graph depicts a simulation run with standard input tables (see text).

are in unlimited supply. The cost of processing (*C*) is the metabolic loss of energy during processing, or in other words, the collective respiratory expenditure by the biomass involved in a particular process.

The variable $r_{potential}$ is a specific growth rate, the potential to expand the process biomass per unit biomass in the absence of resource limitation and negative effects from other processes. It is analogous to the intrinsic rate of natural increase, a population parameter defined by Birch (1948). Therefore, $r_{potential}$ is a function of physical processes that act in a density-independent way, and theoretically is unaffected by density-dependent factors, as long as the qualitative aspects of the process capacity does not change. In the M & C Stream Model, $r_{potential}$ is a function of temperature because both $D(k)$ and $C(k)$ vary with changes in temperature.

Process production for consumers is defined as the net elaboration of the biomass involved in a process regardless of the fate of that biomass during the period under consideration. Bioenergetically, it is assimilation by organisms involved in a process (i.e., the amount of a resource incorporated into process biomass) minus the cost of processing. Consequently, process production for consumer functional groups is analogous to the concept of secondary production (Ricker, 1958). Production for process *i* per unit biomass is derived from the expression:

$$r_{prod}(k)_i = \frac{a_i F_i(k) - C_i(k)}{x_i(k)} \quad , \qquad (2)$$

where $F_i(k)$ is the realized consumption of food resources at time k (i.e., the actual rate at which resources are consumed by the process under existing conditions), and the other symbols are defined for equation (1). It follows that the process production rate at time k is $\{a_i F_i(k) - C_i(k)\}$ or $r_{prod} x(k)$. Therefore, $r_{potential}$ is a specific growth rate with unlimited resources, and r_{prod} is the corresponding rate when resources vary according to system dynamics.

The actual or realized specific growth rate of the process biomass can be obtained after accounting for export and interactions with other processes. For primary consumers (grazers, shredders, and collectors), the equations are:

$$r_{emer}(k)_i = \frac{a_i F_i(k) - C_i(k) - E_i(k)}{x_i(k)} , \tag{3}$$

$$r_{ipred}(k)_i = \frac{a_i F_i(k) - C_i(k) - E_i(k) - I_i(k)}{x_i(k)} , \textit{ and} \tag{4}$$

$$r_{real}(k)_i = \frac{a_i F_i(k) - C_i(k) - E_i(k) - I_i(k) - V_i(k)}{x_i(k)} , \tag{5}$$

where

$E_i(k)$ = insect emergence losses for process *i* at time k,

$I_i(k)$ = process *i* biomass losses to invertebrate predators at time k,

$V_i(k)$ = process *i* biomass losses to vertebrate predators at time k.

In the M & C Stream Model, *E*, *I*, and *V* are usually expressed as a daily rate; and r_{emer}, r_{ipred}, and r_{real} are corresponding specific growth rates after the designated losses are substracted from the process production rate. In particular, r_{real} represents the actual specific growth rate of the process biomass under the conditions specified by the system inputs; it is equal to the process production rate minus all rates that represent losses of process biomass, divided by the process biomass. In the model, bacterial biomass is not tracked, and losses from decomposition of process biomass are included in *C*, the term that represents the cost of processing. For the processes of invertebrate predation and vertebrate predation, corresponding equations in the model for the realized specific growth rate of the process biomass, respectively, are:

$$r_{real}(k)_6 = \frac{a_6 F_6(k) - C_6(k) - E_6(k) - V_6(k)}{x_6(k)} \text{ , and} \tag{6}$$

$$r_{real}(k)_5 = \frac{a_5 F_5(k) - C_5(k) - M(k)}{x_5(k)} \text{ ,} \tag{7}$$

where $M(k)$ is the natural mortality rate for vertebrate predators at time k, and x_6 and x_5 are process biomasses for invertebrate and vertebrate predators, respectively. The realized growth rate of the process biomass at time k is always equal to $r_{real}(k)_i x_i(k)$, where x_i is the biomass associated with the process under consideration. If the system is in a steady state relative to the time resolution under consideration (i.e., energy inputs equal energy losses), $r_{real}(k)_i x_i(k)$ will fluctuate around a mean of zero.

Concepts related to the dynamics of autotrophic processes are similar to concepts presented for consumer processes. When light energy, nutrients, and space are not limiting,

$$r_{potential}(k)_7 = \frac{P_{max}(k) - C_7(k)}{x_7(k)} \quad , \tag{8}$$

where P_{max} is the rate of gross primary production when resources are in unlimited supply. Here, $r_{potential}$ is the specific growth rate of the periphyton assemblage in the absence of grazing and when light energy inputs and the nutrient supply are optimum. In the M & C Stream Model, $r_{potential}$ is a function of temperature. When resources vary with system dynamics,

$$r_{nprod}(k)_7 = \frac{P_{gross}(k) - C_7(k)}{x_7(k)} \quad , \tag{9}$$

where P_{gross} is the realized rate of gross primary production. If the process represents the function of autotrophic organisms only, the rate of net primary production at time k is $r_{nprod}(k)_7 x_7(k)$. For aquatic ecosystems, it is often convenient to include the activities of tightly coupled heterotrophic microorganisms within the process boundary, as in the case of periphyton assemblages in the M & C Stream Model. If this is done, $r_{nprod}(k)_7 x_7(k)$ represents a net elaboration of periphyton biomass -- not net primary production, and C_7, the cost of processing, expresses the integrated metabolic losses from the activities of both autotrophic and heterotrophic microorganisms. Expressions analogous to equations (3) and (5) are:

$$r_{export}(k)_7 = \frac{P_{gross}(k) - C_7(k) - E_7(k)}{x_7(k)} \quad , \textit{and} \tag{10}$$

$$r_{real}(k)_7 = \frac{P_{gross}(k) - C_7(k) - E_7(k) - H_7(k)}{x_7(k)} \quad . \tag{11}$$

In this case, E_7 represents the rate at which periphyton biomass is exported from the assemblage, H_7 is the rate at which periphyton biomass is consumed by grazers, and the other symbols are defined above. For periphyton assemblages, r_{real} is the realized specific growth rate of the periphyton biomass. In the model, the trajectory of this variable varies with changes in parameters and system inputs.

Process Regulation

The r-variables defined in the previous section provide a convenient basis for the investigation of process regulatory mechanisms in large ecosystem models. As yet, the value of such variables for use in field research is unexplored. For the M & C Stream Model, regulatory effects associated with primary consumer processes (grazing, shredding, and collecting) are found from equations 1 - 5, where

$r_{potential} - r_{prod}$ *is the regulatory effect of food resource limitation*;
$r_{prod} - r_{emer}$ *is the regulatory effect of emergence losses*;
$r_{emer} - r_{ipred}$ *is the regulatory effect of invertebrate predation*; and
$r_{ipred} - r_{real}$ *is the regulatory effect of vertebrate predation.*

To analyze state variable dynamics, simply plot $r_{potential}$, r_{prod}, r_{emer}, r_{ipred}, and r_{real} against time and examine the **areas between the curves** relative to a plot of the corresponding state variable. Relationships for the process of invertebrate predation are the same with the exception that

r_{emer} - r_{real} *is the regulatory effect of vertebrate predation,*

and the r_{ipred} term is eliminated. For vertebrate predation,

$r_{potential}$ - r_{real} *is the regulatory effect of food resource limitation and natural mortality*;

and for the periphyton assemblage,

$r_{potential}$ - r_{nprod} *is the regulatory effect of light energy and nutrient limitation*;
r_{nprod} - r_{export} *is the regulatory effect of periphyton export*;
r_{export} - r_{real} *is the regulatory effect of grazing.*

In summary, plots of r-variables can provide useful insights into model behavior, and if used to help understand state variable dynamics, also can serve as a basis for generating hypotheses that relate to regulatory mechanisms in natural streams.

An Example

The *r* variables introduced in the sections above can be specified as output variables (*y* variables in the FLEX notation) for simulation runs with the M & C Stream Model. To generate an example of this output, type

C:\MODEL\STAND > **stream** (return)

After the CMD > prompt is displayed on the screen, type

CMD > **read=stream.cmd** (return)

CMD > **dfile=grazer.dmp** (return)

CMD > **dint=1** (return)

CMD > **dset=x(2),y(1,15:18)** (return)

CMD > **run** (return)

The **run** command will produce the same screen output generated by the commands described for the Standard Run on page 11. However, in this case, a separate dump file (GRAZER.DMP) will be stored in the MODEL\STAND subdirectory or in any other directory or subdirectory specified by the dfile command. GRAZER.DMP contains 7 columns of numbers with 361 rows representing, from left to right, the day number (0 to 360), grazer biomass $[x_2(k)]$, $[r_{potential}(k)_2]$, $[r_{prod}(k)_2]$, $[r_{emer}(k)_2]$, $[r_{ipred}(k)_2]$, and $[r_{real}(k)_2]$. In this example, the state variable($\mathbf{x_2}$) and the r-variables correspond to the process of grazing. In the M & C Stream Model, all *r* variables are calculated as y functions and are treated as output variables that are available to the user through the **sset** (screen output), **pset** (output file), or **dset** (dump file) commands. A list of r-variables and their corresponding *y* variables are presented in Table 2 for the processes of grazing, shredding, collecting, invertebrate predation, vertebrate predation, and primary production. Also, the user can refer to the mathematical documentation for y functions on pages 177-186 of Appendix I.

Table 2 can be used to determine the *y* variables required for any or all of the six major biological processes represented by the model. The example above lists commands corresponding to the process of grazing. If the user wants to examine the process of shredding in detail, the **d** commands are

CMD > **dfile=shred.dmp** [or any desired name] (return)

CMD > **dint=1** (return)

CMD > **dset=x(3),y(18:23)** (return)

Of course, the output can include more than one process. If the processes of collecting, vertebrate predation, and primary production are under investigation, the dump file is specified by

CMD > dset=x(4,5,7),y(24:28,33,36,37:41) (return)

In the examples above, the requested time resolution for the dump file is one day, because this resolution will give the smoothest possible curve in a plot of the variables against time.

Table 2. A list of *r* variables and their corresponding y functions for the major biological processes represented by the M & C Stream Model. The table also indicates the page in the mathematical documentation that corresponds to each *y* function.

Process	r-variable	y-function	Documentation Page
Grazing	$r_{potential}(k)_2$ $r_{prod}(k)_2$ $r_{emer}(k)_2$ $r_{ipred}(k)_2$ $r_{real}(k)_2$	y_2 y_{15} y_{16} y_{17} y_{18}	177 177 178 178 178
Shredding	$r_{potential}(k)_3$ $r_{prod}(k)_3$ $r_{emer}(k)_3$ $r_{ipred}(k)_3$ $r_{real}(k)_3$	y_{19} y_{20} y_{21} y_{22} y_{23}	179 179 179 180 180
Collecting	$r_{potential}(k)_4$ $r_{prod}(k)_4$ $r_{emer}(k)_4$ $r_{ipred}(k)_4$ $r_{real}(k)_4$	y_{24} y_{25} y_{26} y_{27} y_{28}	180 181 181 181 182
Invertebrate Predation	$r_{potential}(k)_6$ $r_{prod}(k)_6$ $r_{emer}(k)_6$ $r_{real}(k)_6$	y_{29} y_{30} y_{31} y_{32}	182 182 183 183
Vertebrate Predation	$r_{potential}(k)_5$ $r_{real}(k)_5$	y_{33} y_{36}	183 185
Primary Production	$r_{potential}(k)_7$ $r_{nprod}(k)_7$ $r_{export}(k)_7$ $r_{real}(k)_7$	y_{37} y_{38} y_{40} y_{41}	185 185 186 186

If the size of the dump file is larger than the user desires, the time resolution can be increased to the desired interval with the **dint** command. Also, it may be desirable to eliminate row 1 of the dump file before reading the file into a plotting program, as values at time zero are all set to a zero value.

Plots of state variables and corresponding plots of r-variables for the processes of grazing, shredding, collecting, and invertebrate predation are presented in Figures 3, 4, and 5. These graphs were made by importing dump files generated by the Standard Run into SIGMAPLOT, a product by Jandel Scientific Software (San Rafael, CA). Any software graphics package that can import ASCII files can be used for plotting dump file output from the FLEX model processor.

In Figure 3, the model predicts that grazer biomass, under conditions of the Standard Run, is maximum early in the year (between days 50 and 100), is relatively low throughout the summer months and early fall, and reaches another maximum in October. Mechanisms accounting for this behavior are revealed in Figure 4A. In this plot, the area between the curves representing $r_{potential}$ and r_{prod} is quite large compared to the areas between the other curves on the graph, indicating that the process of grazing is primarily food resource limited, particularly during the summer months when the riparian canopy reduces light energy inputs into the system. In contrast, the processes of shredding and collecting are regulated more by emergence losses and predation than by food resources (Fig. 4B and 5A), because areas represented by r_{ipred} - r_{real}, r_{emer} - r_{ipred}, and r_{prod} - r_{emer} are greater during most of the simulation period than the area represented by $r_{potential}$ - r_{prod}.

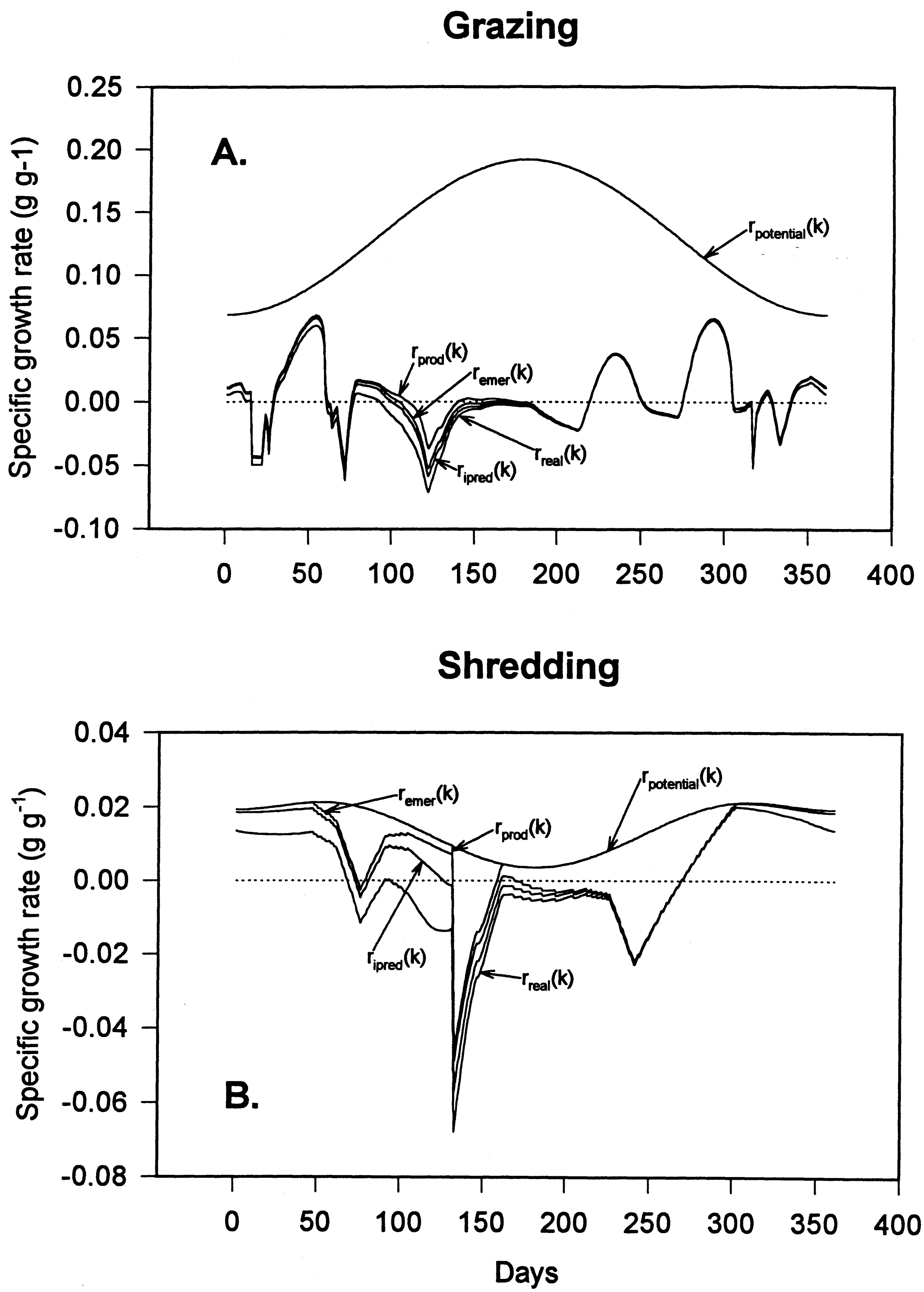


Figure 4. A set of specific growth rates (see text) generated from the Standard Run of Version I of the McIntire & Colby Stream Model for the processes of grazing (A) and shredding (B).

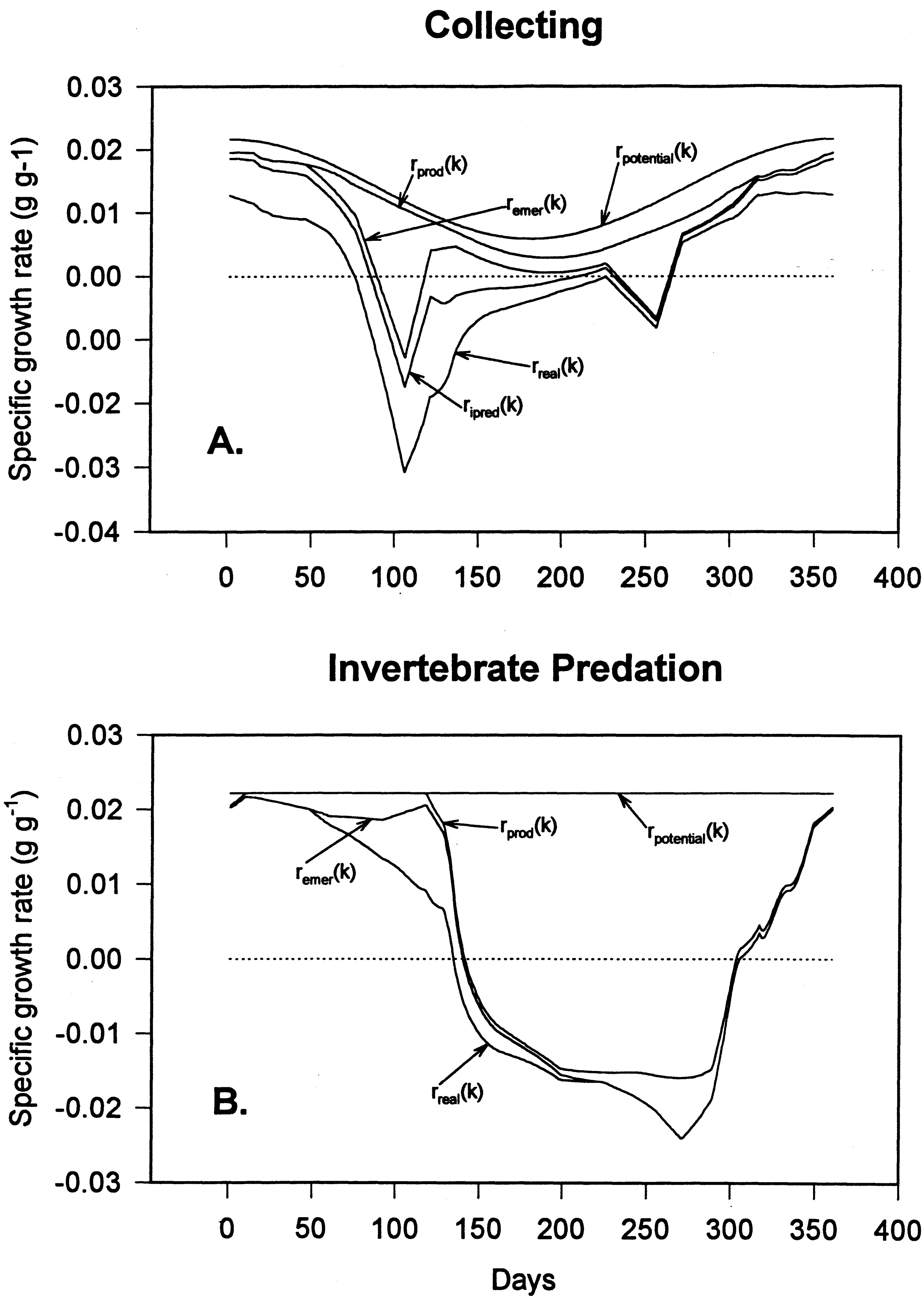


Figure 5. A set of specific growth rates (see text) generated from the Standard Run of Version I of M & C Stream Model for the processes of collecting (A) and invertebrate predation (B).

One of the strengths of the r-variable analysis is that the curves can reveal temporal changes in mechanisms that control state variable dynamics. For example, Figure 4B clearly illustrates that the process of shredding during the Standard Run is controlled by emergence losses and predation early in the year, expriences a brief period of food limitation, and then is limited mostly by emergence losses for the rest of the year. The period of food limitation is identified by the separation between the curves for $r_{potential}$ and r_{prod}; in this case, the curves are the same except for the segment between days 125 and 160 (Fig. 4B). In the Standard Run, the process of invertebrate predation exhibits a different pattern than the other processes: it is influenced by emergence and vertebrate predation up until day 140 and then is mostly controlled by the availability of food resources for the rest of the year (Fig. 5B).

THE M & C STREAM MODEL: HERBIVORY VERSION

Introduction

This section briefly describes the structure of the Herbivory Version of the M & C Stream model and provides instructions for obtaining some representative output. This version of the model is a modification of Version I that evolved in response to a research program designed to investigate the process of herbivory in lotic ecosystems. This version also illustrates the flexibility of the M & C Stream Model by providing an example of how individual subsystems, in this case the Herbivory subsystem, can be expanded to meet the need of a set of research objectives. In particular, model development involved the isolation of the Herbivory subsystem of Version I and the elaboration of its mathematical structure in relation to some recent experimental work with laboratory streams (Steinman and McIntire, 1986;

Steinman et al., 1987). The strategy used to develop the Herbivory Version of the M & C Stream model involved:

1. identification of the input variables related to the Herbivory subsystem of Version I of the M & C Stream Model;

2. generation of input tables for the Herbivory subsystem from the Standard Run of Version I of the M & C Stream model;

3. isolation of the Herbivory subsystem of Version I for modification and study;

4. a Standard Run of the Herbivory subsystem of Version I in isolation using the input tables compiled from the dump files produced by step 2;

5. comparison of output from step 4 with corresponding output from the Standard Run of Version I of the model to assure identical tracking between the isolated Herbivory subsytem model and the Herbivory subsystem integrated into the total ecosystem model;

6. utilization of new experimental results to modify and update the structure of the isolated Herbivory subsystem model;

7. investigation of the updated Herbivory subsystem model in isolation from the total ecosystem model (Version I) relative to selected parameters and inputs;

8. replacement of the old Herbivory subsystem in Version I with the updated version of the Herbivory subsytem in the total ecosystem model; and

9. investigation of the updated total ecosystem model, referred to here as the Herbivory Version of the M & C Stream Model, relative to selected parameters and inputs.

The Herbivory Version of the M & C Stream Model and supporting files included on the enclosed diskette are found in the HERB subdirectory and allow the user to participate in the investigation of the updated total ecosystem model relative to changes in selected parameters and input tables (step 9 above). A complete mathematical documentation of the Herbivory Version is included in Appendix V (page 211).

In Version I of the M & C Stream Model , the Herbivory subsystem contains subsystems that represent the processes of primary production and grazing (Fig. 1). The state variable in each of these subsystems is the biomass that is involved in the corresponding process at any time. New data from experimental work with laboratory streams (Steinman and McIntire, 1986, 1987; Steinman *et al.*, 1987) allowed the state variable inside the Primary Production subsystem to be partitioned into three new state variables that are related to the taxonomic composition and successional state of the algal biomass. In this case, the state variables represent the collective biomasses of filamentous and coenobic chlorophytes, diatoms, and cyanobacteria (blue-green algae) along with epiphytic heterotrophic microorganisms. In addition, data from recent feeding experiments by Lamberti *et al.* (1995) provide a preliminary basis for establishing a quantitative relationship between the relative abundance of the three algal functional groups and the food consumption rates and assimilation efficiencies associated with the process of grazing.

In summary, the Herbivory Version of the M & C Stream Model now tracks the successional trajectory and production dynamics of the algal assemblage as well as the response of grazers to corresponding changes in food quality and quantity. This representation also expresses the feedback control that the process of grazing has on successional changes within the algal assemblage.

Structure of the Herbivory Version of the M & C Stream Model

The Herbivory Version of the M & C Stream Model has 17 state variables. In addition to the 14 state variables in Version I, the Herbivory Version has three other variables that partition the periphyton biomass (x_7) into three different taxonomic groups: diatoms (x_{15}), cyanobacteria (x_{16}), and chlorophytes (x_{17}). In other words, $x_7 = (x_{15} + x_{16} + x_{17})$.

The mathematical structure of the Herbivory Version of the model (Appendix V) is essentially the same as the structure of Version I (Appendix I), with the exception of the Herbivory subsystem which has been modified to introduce the three algal functional groups and their influence on the process of grazing. A mathematical documentation and programming details associated with the modifications in the Herbivory subsystem are presented in Appendix V (page 211). The algorithm that introduces the new information into the Herbivory subsystem has the following characteristics:

1. Primary production is modeled according to the mathematical relationships described by McIntire and Colby (1978). (Calculations of photosynthesis, respiratory expenditures, and export losses are based on the total periphyton biomass -- not the biomass of individual algal functional groups.)

2. The update increment from primary production is partitioned among the algal functional groups according to the following rules:

   (a) If the irradiance is < 30 μmol m^{-2} s^{-1} or the periphyton biomass is < 2 g m^{-2}, the update increment is 100% diatoms;

   (b) If irradiance is > 30 and < 100 μmol m^{-2} s^{-1}, there is a linear relationship between light energy and the proportion of diatoms and cyanobacteria in the update increment, reaching a maximum of 19% cyanobacteria at 50 μmol m^{-2} s^{-1} when the periphyton biomass is 5 g m^{-2};

(c) If irradiance is > 150 μmol m^{-2} s^{-1}, chlorophytes, diatoms, and cyanobacteria are all part of the update increment; and

(d) At light saturation (> 300 μmol m^{-2} s^{-1}), the periphyton biomass will eventually assume a composition of 48% diatoms, 48% chlorophytes, and 4% cyanobacteria when the periphyton biomass is > 45 g m^{-2}.

3. The assimilation efficiency and a food quality limiting factor associated with the process of grazing are a function of the proportion of diatoms in the algal assemblage according to the following rules:

(a) Assimilation efficiency is a linear function of the proportion of diatoms in the assemblage, varying between 0.53 (48% diatoms) and 0.73 (100% diatoms); and

(b) A food quality limiting factor expressed as a proportional adjustment of the food demand (i.e., the food consumption rate with an optimum diet and unlimited food supply) is a linear function of the proportion of diatoms in the assemblage, varying 0.28 and 1.00, depending on the proportional abundance of diatoms and a parameter that determines the impact of food quality on food consumption. The rate of grazing is adjusted to the composition of the periphyton assemblage by multiplying the food demand by the food quality limiting factor.

Simulation Procdures

This section describes the procedures for obtaining output from the Herbivory Version of the M & C Stream Model. The behavior of the system with and without grazing and with standard input tables for Version I of the model (page 8) is examined first. Next, a list of selected parameters is introduced and described to help the user study other aspects of system dynamics. Finally, examples of output generated by changing selected parameters and input tables are provided along with corresponding energy budget tables. Simulation procedures described in this section assume that the user is familiar with the material introduced for Version I of the model in the earlier sections of this tutorial.

Log on the root directory of the C drive of your computer, insert the enclosed diskette into the A drive slot, and type

C:\>**cd model** (return)

C:\MODEL>**md herb** (return)

C:\MODEL>**cd herb** (return)

C:\MODEL\HERB>**copy a:\herb*.*** (return)

C:\MODEL\HERB>**dir** (return)

These commands create a new subdirectory for the MODEL directory and copy the files needed to run the Herbivory Version of the M & C Stream Model on the new MODEL\HERB subdirectory. The **dir** command provides a list of all files needed to run the Herbivory Version. For this version, the input files are the same as those used to run Version I of the model (see page 8 for a list and description).

To run the model, type

C:\MODEL\HERB>**herb** (return)

CMD>**read=herb.cmd** (return)

CMD>**run** (return)

CMD>**q** (return)

These commands activate the FLEX model processor for the Herbivory Version of the model

(HERB.COM). The **read=herb.cmd** command then reads in the command file for the Standard Run of this version of the model, and the **run** command initiates the corresponding simulation run. In this case, the command file is set up as follows:

```
line 1:    LEVEL=1
line 2:    IB(1:10)=0,1.39E-2,5.7E-2,-1,0,0.114,0.581,1.97E-4,-94.4,9.42E3
line 3:    IB(11:20)=1.08E3,4.88E-2,8.83E-2,10.2,2.95E-3,1.07,0.633,1.1,1.6E2,1.5
line 4:    IB(21:30)=4,0.8,1,4,0.5,0,0,3.5,3.5,0
line 5:    IB(31:40)=9.95E-2,0.465,0.895,0.56,1.9,1.51,0.294,2.03,1.28E-4,1.28E-4
line 6:    IB(41:50)=1.38E-3,1.38E-3,-1,0,0.187,2.33E-3,1.74E-2,0,0,0.3
line 7:    IB(51:60)=0.86,0.1,1.87E-3,2.5E-3,2.6E-2,1.88E-2,0.42,0.82,0.05,100
line 8:    IB(61:70)=0,0,0,3,0.01,2.8E-2,0.583,1.0E-3,0.5,1.92E-2
line 9:    IB(71:80)=2.1E-3,0.7,0,7.4E-3,1.08E-3,0.1,0.4,2.68E2,2.95,0.187
line 10:   IB(81:90)=1.46E-2,2.96E-2,1.46E-2,15,0.8,12,0.35,0.7,0.237,1.0E3
line 11:   IB(91:100)=2.4E3,0.55,0.18,0.21,0,0.3,0.3,0.3,0.167,1
line 12:   IB(101:107)=4.46E-3,4.46E-3,4.46E-3,-1,1.44E-4,0,5.85E-2
line 13:   IB(108:114)=9.11E-4,1.99E-4,5.85E-2,-1,-1,-1,-1
line 14:   IB(115:121)=3.0E-2,1.75E-2,2.5E-2,-2.83E-2,.849,1.0,.28
line 15:   IX(1:11)=0,1.962,1.304,2.3,4.236,.194,.957,8.764,121.095,24.244,30.851
line 16:   IX(12:17)=1.145,16.978,.668,.957,9.752E-7,1.643E-27
line 17:   IM(2:7)=0.0,0.0,0.0,0.0,0.0,0.0
line 18:   TARGET
line 19:   SSET=X(2:7,15:17)
line 20:   SINT=30
line 21:   SLIST
line 22:   TSTOP=360
line 23:   PFILE=HERB.OUT
line 24:   PSET=X(2:7,15:17)
line 25:   PINT=15
line 26:   TABLE(1)=EXLITE
line 27:   TABLE(2)=XNUTR
line 28:   TABLE(3)=STRFLOW
line 29:   TABLE(4)=SALLOC
line 30:   TABLE(5)=FALLOC
line 31:   TABLE(6)=GEMER
line 32:   TABLE(7)=SEMER
line 33:   TABLE(8)=CEMER
line 34:   TABLE(9)=PEMER
line 35:   TABLE(10)=STRTEMP
line 36:   TABLE(11)=PHOTPER
```

This file is similar to the command file set up for Version I of the model (page 17) with the exception that seven new parameters (**b_{115}, b_{116}, b_{117}, b_{118}, b_{119}, b_{120},** and **b_{121}**) are added as part of the mathematical stucture that represents modifications to the Herbivory subsystem. Moreover, the command file requests a print file entitled HERB.OUT that lists the biomasses of the major consumer processes (x_2, x_3, x_4, x_5, and x_6) and the periphyton biomass (x_7) partitioned into diatoms (x_{15}), cyanobacteria (x_{16}), and chlorophytes (x_{17}). Also, note that the **sint** and **pint** commands set the time intervals for the screen and print file listings at 30 and 15 days, respectively. The input tables (Tables 1 - 11) are the same as those requested for the Standard Run of Version I (see Appendix II for values); they can be changed at any time by the user in response to research needs and the objective questions under consideration.

The output generated by the commands listed above henceforth is referred to as the Standard Run of the Herbivory Version of the M & C Stream Model. To plot state variables from this run, it is necessary to set up a dump file that can be used as an input into a graphics program (e.g., SIGMAPLOT or a spreadsheet package such as QUATTRO PRO). To generate a dump file for the Standard Run of the Herbivory Version of the model, type

C:\MODEL\HERB>**herb** (return)

CMD>**read=herb.cmd** (return)

CMD>**dfile=herbgraz.dmp** (return)

CMD>**dint** (return)

CMD>**dset=x(2:7,15:17)** (return)

CMD>**q** (return)

These commands will produce screen output, a print file entitled HERB.OUT, and a dump file entitled HERBGRAZ.DMP. The print file contains the run title, a list of parameters and input tables, initial values for state variables as well as a list of requested variables at the time resolution designated by the command file, in this case x_2, x_3, x_4, x_5, x_6, x_7, x_{15}, x_{16}, and x_{17} at a time interval of 15 days (see the HERB.CMD command file listed above). The dump file contains only the requested variables, which in this case are the same as the print file at a time resolution of 1 day. In our example, the dump file was set up in the command mode of the model processor. However, the user also has the option of adding the same set of commands to the command file. Usually, it is convenient to include commands that will be used for more than one simulation run in the structure of the command file, and then, after entering the command mode of the model processor, introduce commands that are used only once .

An energy budget for the Standard Run of the Herbivory Version of the M & C Stream Model can be obtained by using the program HERBTAB.COM. This program and its corresponding command file HERBTAB.CMD are similar to HERB.COM and HERB.CMD, respectively, but in addition, these files are used to calculate and request the variables that are required to run BUDGET.COM, the same energy budget program that was introduced with Version I of the model. For comparison of the command files, the user can print out HERBTAB.CMD and HERB.CMD by typing

C:\MODEL\HERB>**print herbtab.cmd** (return)

C:\MODEL\HERB>**print herb.cmd** (return)

To obtain and energy budget for the Standard Run of the Herbivory Version of the Model with grazing, type

C:\MODEL\HERB>**herbtab** (return)

CMD > **read=herbtab.cmd** (return)

CMD > **run** (return)

CMD > **q** (return)

As in the case of Version I, these commands will result in a dump file entitled STREAM.DMP which represents the input information required to run BUDGET.COM. The file containing the output from BUDGET.COM is called STREAM.TAB and is produced by typing

C:\MODEL\HERB > **budget** (return)

At this point, the user is prompted for a simulation number (or run title): "Please enter the simulation number." A corresponding reply might be: (space) **Standard Run With Grazing.** After the reply, the program executes and stores the desired budget in the file STREAM.TAB. The user can get a listing of the budget file by typing

C:\MODEL\HERB > **print stream.tab** (return)

It is recommended that the user delete STREAM.TAB and STREAM.DMP after each run to save space on the hard disk.

As another example, run the Herbivory Version of the model again, this time without the process of grazing. This is done by setting the initial value of the grazer biomass ($\mathbf{x_2}$) equal to zero by typing

C:\MODEL\HERB > **herb** (return)

CMD > **read=herb.cmd** (return)

CMD > **ix(2)=0** (return)

CMD > **tstop=7200** (return)

CMD > **sset=x(2:17)** (return)

CMD>**sint=360** (return)

CMD>**run** (return)

This part of the run allows the system to converge to a new steady state. This is necessary because the initial values for state variables introduced by the command file (HERB.CMD) are the steady state values for the system when the process of grazing is active -- not when the system is running without grazing. Therefore, it is necessary to find the new steady state values by allowing the model to run for a longer period. In this case, a period of 7200 days (20 years) is sufficient to allow the system to converge to a steady state. However, in other cases, changes in model inputs and parameters may require a longer period before steady state values are found. The screen output is set for the interval of 360 days (1 year) so that the user can observe changes in the initial state variable values at the beginning of each year. Furthermore, it is necessary to request that the screen output include values for all 16 state variables (x_2 - x_{17}).

After day 7200 is reached, the simulation stops. At this point, the user must either print the screen or copy down the values listed for the state variables corresponding to day 7200. The next step is to press the return key and type

CMD>**reset** (return)

CMD>**tstop=360** (return)

CMD>**sint=15** (return)

CMD>**ix(2:9)=0,1.328,3.289,3.194,6.192E-2,20.544,6.74,126.009** (return)

CMD>**ix(10:14)=25.027,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=13.881,2.282,4.381** (return)

CMD > **dfile=herbwout.dmp** (return)

CMD > **dint=1** (return)

CMD > **dset=x(2:7,15:17)** (return)

CMD > **run** (return)

These commands will generate a new Standard Run, in this case, a 1-year simulation without grazing after the system has converged to steady state behavior. Again, steady state behavior simply means that the system will exhibit repeatable dynamics as long as the inputs and parameters are not changed. In the case of the Standard Run with or without grazing, the system exhibits an annual cycle such that the state variable values return to their initial values at the beginning of each year. With certain changes in parameters or input tables, the model may exhibit repeatable cycles of 2, 3, or even 4 years because of lag effects.

To obtain an energy budget for the Standard Run without grazing, type

C:\MODEL\HERB > **herbtab** (return)

CMD > **read=herbtab.cmd** (return)

CMD > **ix(2:9)=0,1.328,3.289,3.194,6.192E-2,20.544,6.74,126.009** (return)

CMD > **ix(10:14)=25.027,30.851,1.145,16.978,.668** (return)

CMD > **ix(15:17)=13.881,2.282,4.381** (return)

CMD > **run** (return)

CMD > **q** (return)

These commands will produce another dump file (STREAM.DMP) that can be used as input into the energy budget program BUDGET.COM (see pages 48-49 for commands). (Note: unless the dump file name is changed in the command file HERBTAB.CMD, a new dump file

STREAM.DMP will be written over any previous dump file with the same name.)

Examples of Output from the Standard Run

Plots of state variables for the Standard Run of the Herbivory Version of the model with and without grazing are illustrated in Figures 6, 7, and 8. Corresponding energy budgets are listed in Appendix VIII (page 236). Plots for this tutorial were designed by the program SIGMAPLOT (Jandel Scientific) after importing the dump files obtained from the simulation runs described above.

Output from the Standard Run with grazing indicates that diatoms dominate the algal assemblage when the system is in a steady state and the process of grazing is in equilibrium with available food resources (Fig. 8A). In this case, the model predicts that the algal biomass turns over about 62 times each year, and that annual gross primary production, expressed as organic matter, is 112.56 g m^{-2} of which green algae and cyanobacteria contribute only 3% (Appendix VIII). With the standard set of inputs, annual production of herbivore biomass is 7.2 g m^{-2} (organic matter), with a corresponding turnover of 3.7 times per year (Appendix VIII).

In the absence of grazing (i.e., grazer biomass remains zero), the Standard Run predicts that the annual mean algal biomass is 20 g m^{-2}, and that all three algal groups are prominent in the spring and fall of the year (Appendix VIII, Fig. 8B). Without grazing, annual gross primary production is 530 g m^{-2} of which the diatoms, chlorophytes, and cyanobacteria account for 73.3%, 19.3%, amd 7.4% of this total, respectively. Corresponding annual turnover numbers for these groups are 14.4, 16.1, and 19.4 times per year. Furthermore, annual energy losses from the algal assemblage, without grazing, partition

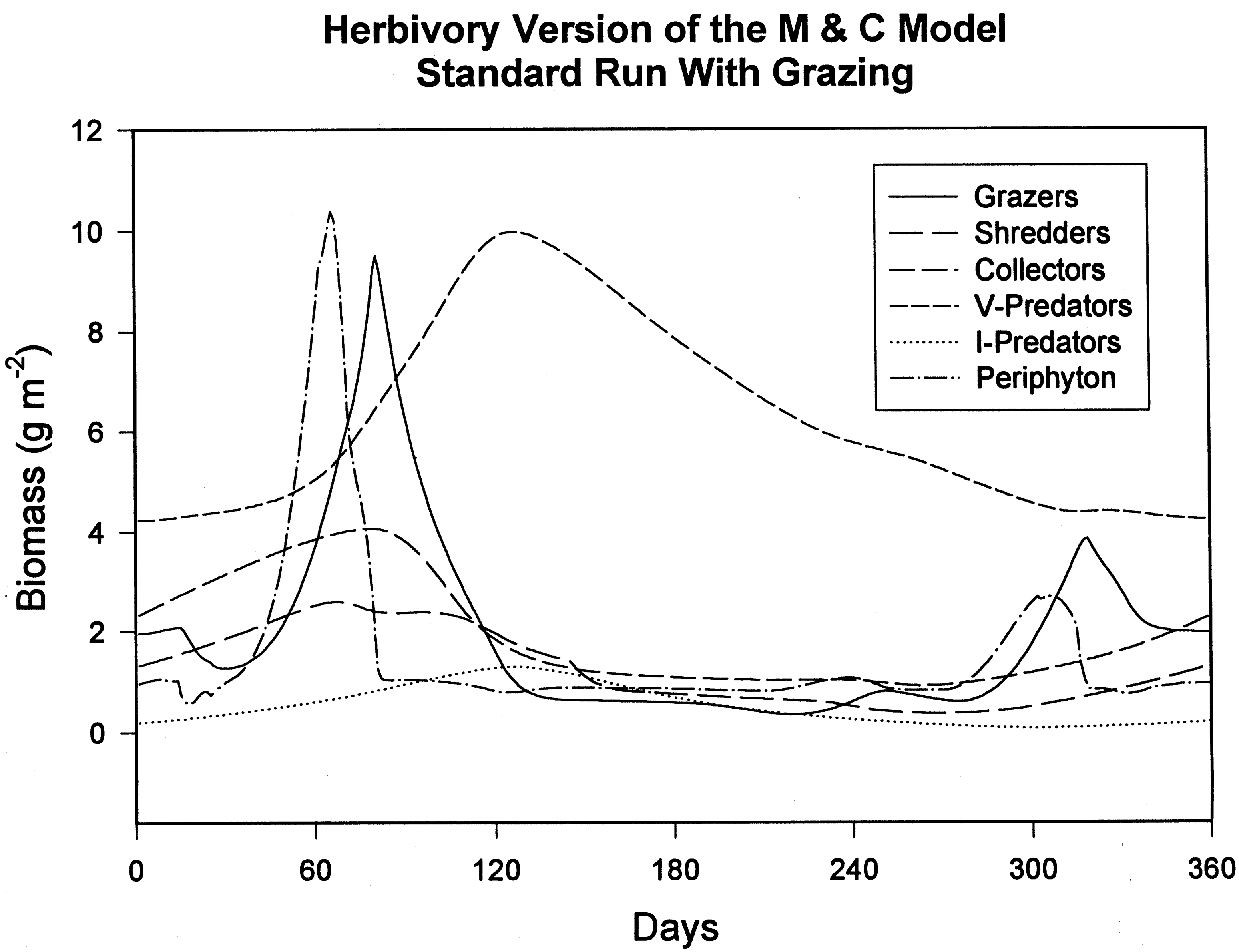


Figure 6. Steady state, seasonal dynamics of state variables representing the major biological processes in the Herbivory Version of the M & C Stream Model. The graph represents output from the Standard Run with grazing.

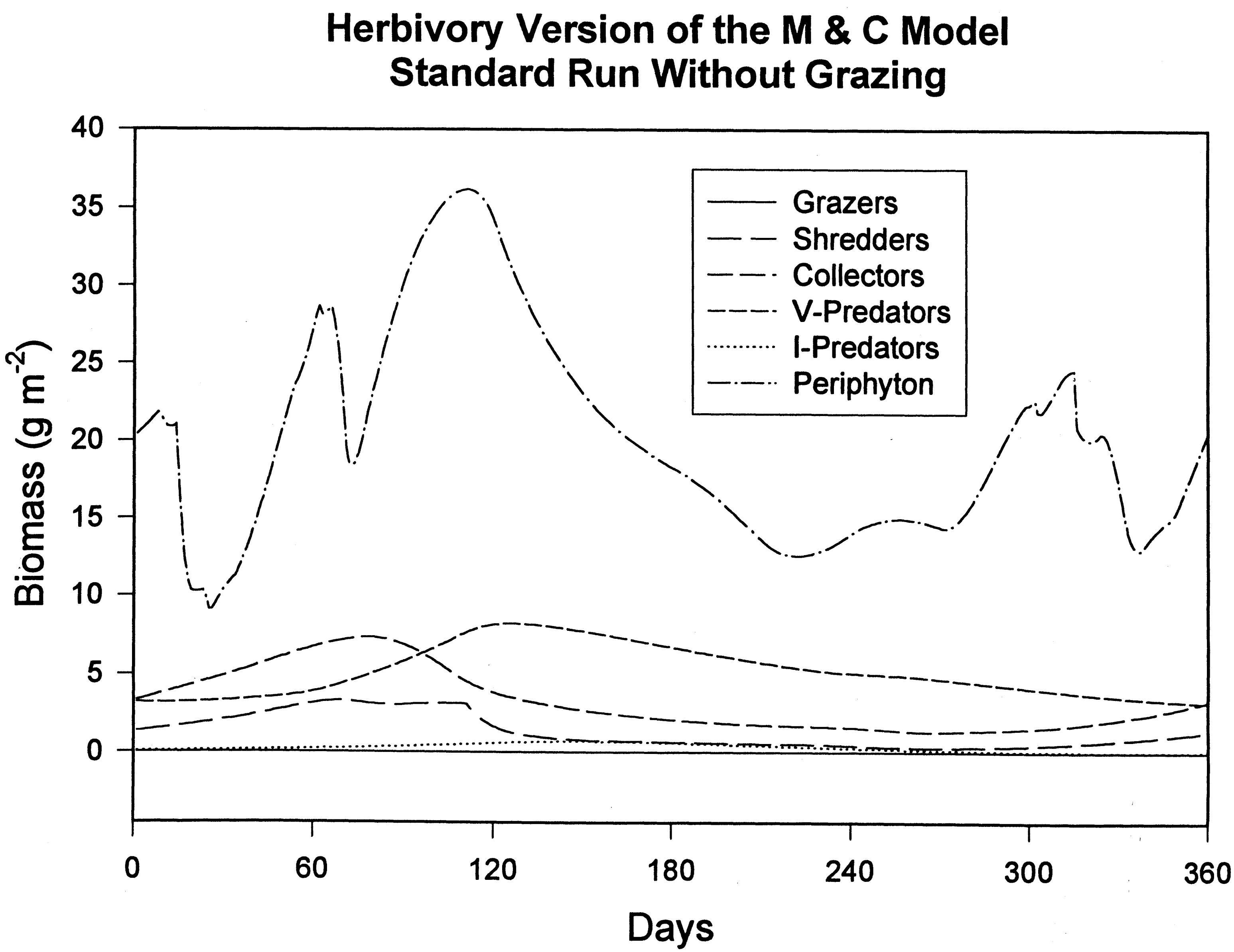


Figure 7. Steady state, seasonal dynamics of state variables representing the major biological processes in the Herbivory Version of the M & C Stream Model. The graph represents output from the Standard Run without grazing.

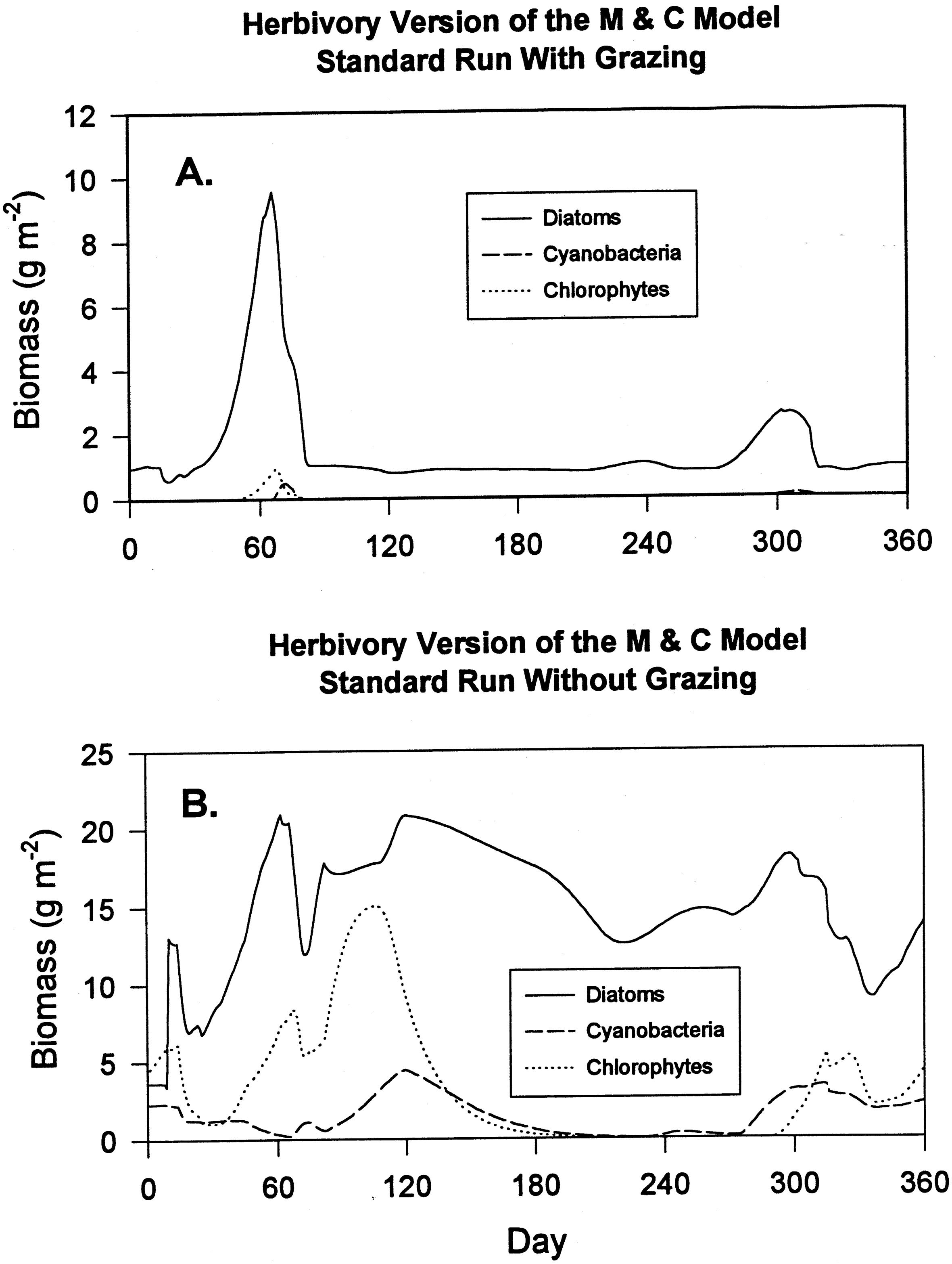


Figure 8. Seasonal dynamics of state variables representing the algal functional groups in the Herbivory Version of the M & C Stream Model. The graph depicts a Standard Run with (A) and without (B) grazing.

into 41.8% respiration, 41.9% particulate export, and 16.4% DOM leakage. In contrast, the Standard Run with grazing indicates that 61.3% of annual gross primary production and 71.7% of annual net periphyton production are consumed by herbivores; corresponding losses from respiration, particulate export, and DOM leakage are 16.4%, 24.0%, and 3.1% of gross primary production, respectively. In the latter case, diatoms lose 62.8% to grazing, while chlorophytes lose only 49.5%, a manifestation of the effects of the food quality limiting factor on consumption rates.

Manipulations of Input Tables and Parameters: Some Examples

In this section, examples of manipulations of parameters and input tables are provided to give the user a chance to practice using the model for addressing a specific set of objective questions. For convenience, the selected parameters listed on pages 20-21 are relisted below along with three new parameters that are introduced in the examples that follow. After working through the examples, the user can create a new set of simulation runs by changing some of the input tables, the parameters below, or some of the other parameters listed in Appendix I and Appendix V.

Parameter	Standard Value	Explanation
$\mathbf{b_{92}}$	0.55	grazer assimilation ratio
$\mathbf{b_{93}}$	0.18	shredder assimilation ratio
$\mathbf{b_{94}}$	0.21	collector assimilation ratio
$\mathbf{b_{58}}$	0.82	invertebrate predator assimilation ratio
$\mathbf{b_{51}}$	0.86	vertebrate predator assimilation ratio
$\mathbf{b_{72}}$	0.7 g m^{-2}	algal refuge parameter
$\mathbf{b_{96}}$	0.3 g m^{-2}	grazer refuge parameter

$\mathbf{b_{97}}$	0.3 g m^{2-2}	shredder refuge parameter
$\mathbf{b_{98}}$	0.3 g m^{-2}	collector refuge parameter
$\mathbf{b_{4}}$	-1	constant temperature
$\mathbf{b_{100}}$	1.0	grazer food demand multiplier
$\mathbf{b_{113}}$	-1	constant irradiance
$\mathbf{b_{111}}$	-1	constant NO_3 (nutrient) concentration
$\mathbf{b_{114}}$	-1	constant allochthonous input (slow lag time)
$\mathbf{b_{104}}$	-1	constant allochthonous input (fast lag time)
$\mathbf{b_{120}}$	1.0	irradiation multiplier
$\mathbf{b_{121}}$	0.28	food quality limiting factor minimum

Example 1: The Algal Refuge Parameter

Assume that you are interested in investigating the response of the model to the protection of the algal food resource from the effects of grazing. Mechanisms in natural streams that could account for such protection include substrate heterogeneity (i.e., access to the resource) and differences in grazer mouthpart morphology. Of course, the qualitative nature of the algal food resource, which is related to age and taxonomic composition, is also involved; but in the Herbivory Version of the model, effects of food quality are controlled by a separate parameter ($\mathbf{b_{122}}$) explained on page 68.

In the Standard Run of the Herbivory Version of the model, the algal refuge parameter $\mathbf{b_{72}}$ is set at 0.7 g m^{-2}. This means that when the algal biomass is 0.7 g m^{-2} or less, the resource is not available for consumption by grazers. In other words, the biomass available to grazers is always $\mathbf{x_7}$ - $\mathbf{b_{72}}$, or in this case $\mathbf{x_7}$ - 0.7 g m^{-2}. To arbitrarily increase the algal refuge from 0.7 to 4.0 g m^{-2}, type

C:\MODEL\HERB>**herb** (return)

CMD>**read=herb.cmd** (return)

CMD>**ib(72)=4.0** (return)

CMD>**sset=x(2:17)** (return)

CMD>**tstop=7200** (return)

CMD>**sint=360** (return)

CMD>**run** (return)

After copying down the steady state values for the state variables, press the return key and type

CMD>**reset** (return)

CMD>**tstop=360** (return)

CMD>**sint=15** (return)

CMD>**sset=x(2:7,15:17)** (return)

CMD>**ix(2:9)=4.656,.915,.968,5.291,.483,5.727,9.19,151.848** (return)

CMD>**ix(10:14)=29.428,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=5.141,.586,1.156E-17** (return)

CMD>**dfile=refuge4.dmp** (return)

CMD>**dint=1** (return)

CMD>**dset=x(2:7,15:17)** (return)

CMD>**run** (return)

CMD>**q** (return)

After leaving the FLEX model processor the user can print and examine the print file

HERB.OUT, and then generate plots of state variables by importing the dump file REFUGE4.DMP into a plotting program of choice. Plots of state variables for this run are illustrated in Figures 9 and 10A. A corresponding annual energy budget for this simulation run is obtained by typing

C:\MODEL\HERB>**herbtab** (return)

CMD>**read=herbtab.cmd** (return)

CMD>**ib(72)=4.0** (return)

CMD>**ix(2:9)=4.656,.915,.968,5.291,.483,5.727,9.19,151.848** (return)

CMD>**ix(10:14)=29.428,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=5.141,.586,1.156E-17** (return)

CMD>**run** (return)

CMD>**q** (return)

C:\MODEL\HERB>**budget** (return)

(Enter run title) (return)

To continue the investigation of the effects of changing the algal refuge parameter, set b_{72} equal to 10 g m^{-2} and make another simulation run. In this case, the commands are

C:\MODEL\HERB>**herb** (return)

CMD>**read=herb.cmd** (return)

CMD>**ib(72)=10.0** (return)

CMD>**tstop=7200** (return)

CMD>**sint=360** (return)

CMD>**sset=x(2:17)** (return)

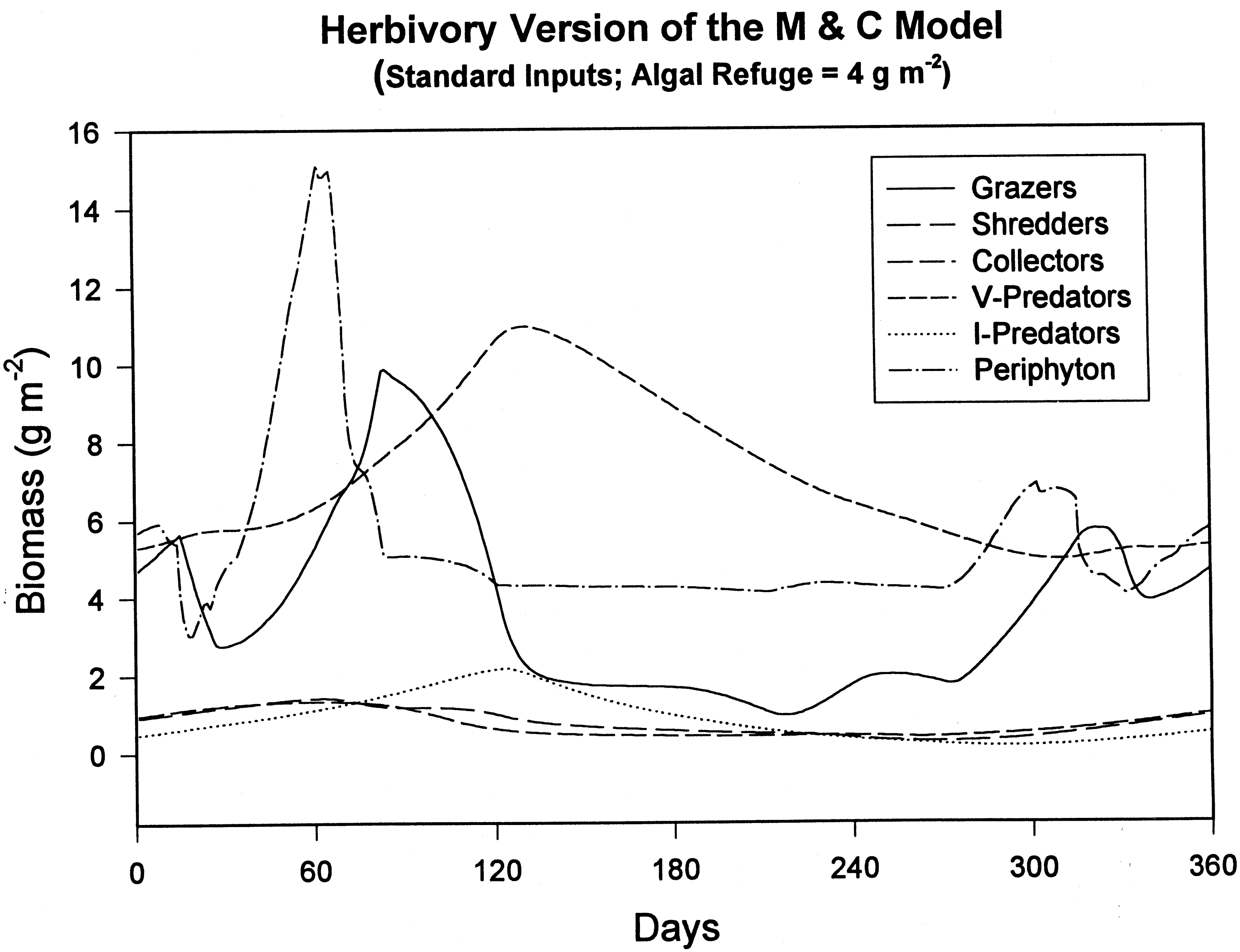


Figure 9. Seasonal dynamics of state variables representing the major biological processes in the Herbivroy Version of the M & C Stream Model. The run conditions are: standard input tables; algal refuge = 4 g m^{-2}.

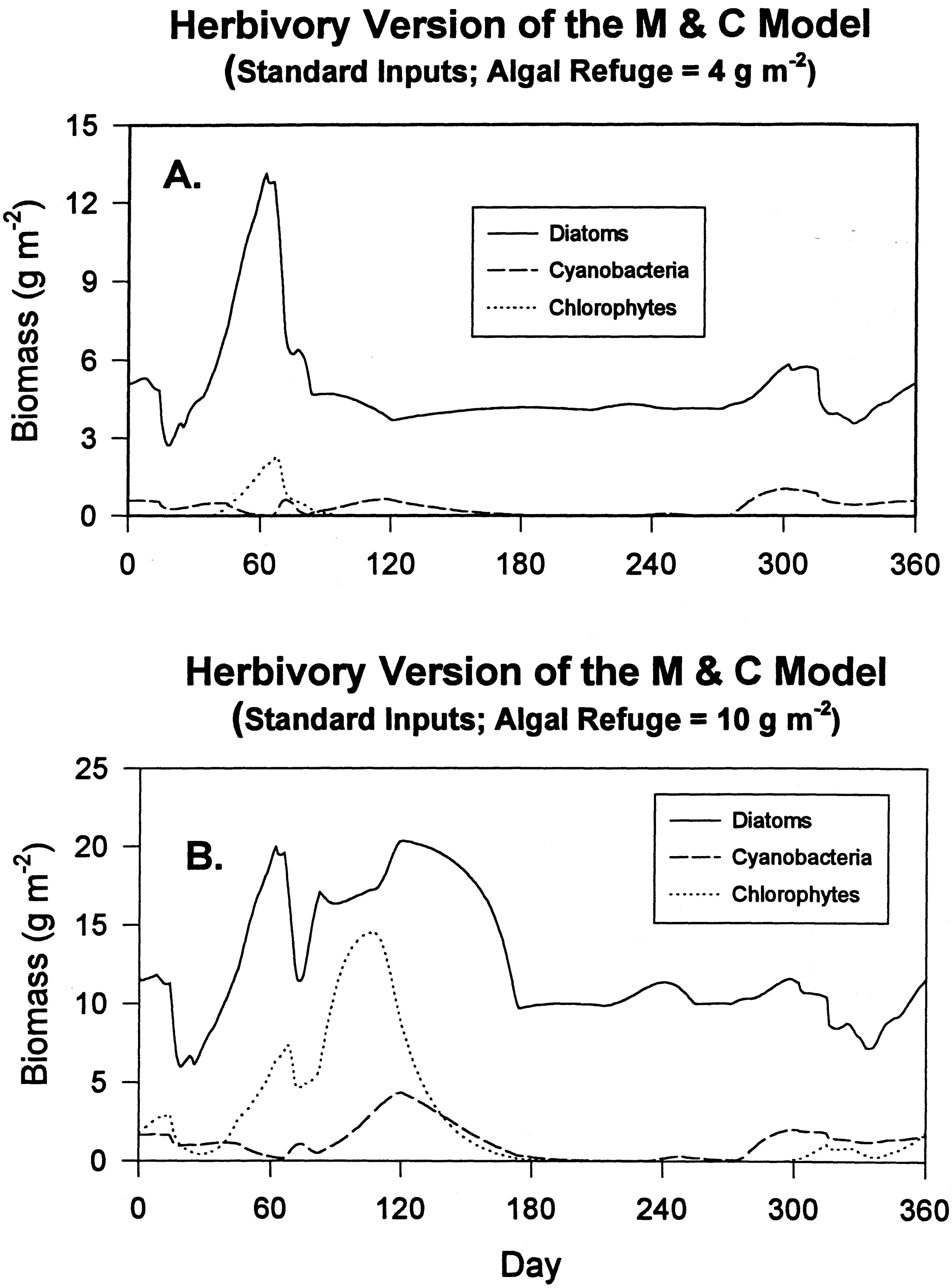


Figure 10. Seasonal dynamics of state variables representing the algal functional groups in the Herbivory Version of the M & C Stream Model. The run conditions are: algal refuge equal to 4 g m^{-2} (A) and 10 g m^{-2} (B).

```
CMD > run                                                                (return)
(Write down state variable values for day 7200)                          (return)
CMD > reset                                                              (return)
CMD > tstop=360                                                          (return)
CMD > sint=15                                                            (return)
CMD > sset=x(2:7,15:17)                                                  (return)
CMD > ix(2:9)=2.692,1.458,1.715,3.263,.65,15.053,11.946,113.285          (return)
CMD > ix(10:14)=22.832,30.851,1.145,16.978,.668                          (return)
CMD > ix(15:17)=11.589,1.642,1.822                                       (return)
CMD > dfile=refuge10.dmp                                                 (return)
CMD > dint=1                                                             (return)
CMD > dset=x(2:7,15:17)                                                  (return)
CMD > run                                                                (return)
CMD > q                                                                  (return)
C:\MODEL\HERB > herbtab                                                  (return)
CMD > read=herbtab.cmd                                                   (return)
CMD > ib(72)=10.0                                                        (return)
CMD > ix(2:9)=2.692,1.458,1.715,3.263,.65,15.053,11.946,113.285          (return)
CMD > ix(10:14)=22.832,30.851,1.145,16.978,.668                          (return)
CMD > ix(15:17)=11.589,1.642,1.822                                       (return)
CMD > run                                                                (return)
CMD > q                                                                  (return)
```

C:\MODEL\HERB > **budget** (return)

(Enter run title) (return)

The corresponding plots of state variables for an algal refuge of 10 g m^{-2} are illustrated in Figures 10B and 11.

If these simulation runs are continued until an entire set of refuge values ranging from the standard value (b_{72} = 0.7 g m^{-2}) to a value at which the system no longer supports grazing (b_{72} = 15.0 g m^{-2}), it is possible to determine the refuge value that optimizes grazer production (Fig. 12A) and the production of other consumer functional groups (Fig. 12B). With the standard set of inputs, annual grazer production and annual mean biomass of grazers are greatest at an algal refuge of 5 g m^{-2} after the system reaches steady state behavior. These results suggest that secondary production can be limited by over exploitation of food resources under some circumstances. The model also predicts that at refuge values above 5 g m^{-2}, green algae account for a larger proportion of the algal biomass (e.g., Fig. 10B), a factor that lowers food quality and further contributes to a decline in secondary production (Fig. 12A). As the algal refuge approaches 15 g m^{-2}, secondary production in the Herbivory subsystem goes to zero and algal production reaches its maximum annual rate of 530 g m^{2} because grazer losses to emergence and predation exceed the gains through assimilation of algal biomass at this refuge level.

Up to now, the analysis of model output has focused on the Herbivory subsystem, i.e., the processes of grazing and primary production. The user can expand this investigation by examining model output further in relation to indirect effects of algal refuge on the processes of shredding, collecting, invertebrate predation, and vertebrate predation. These indirect

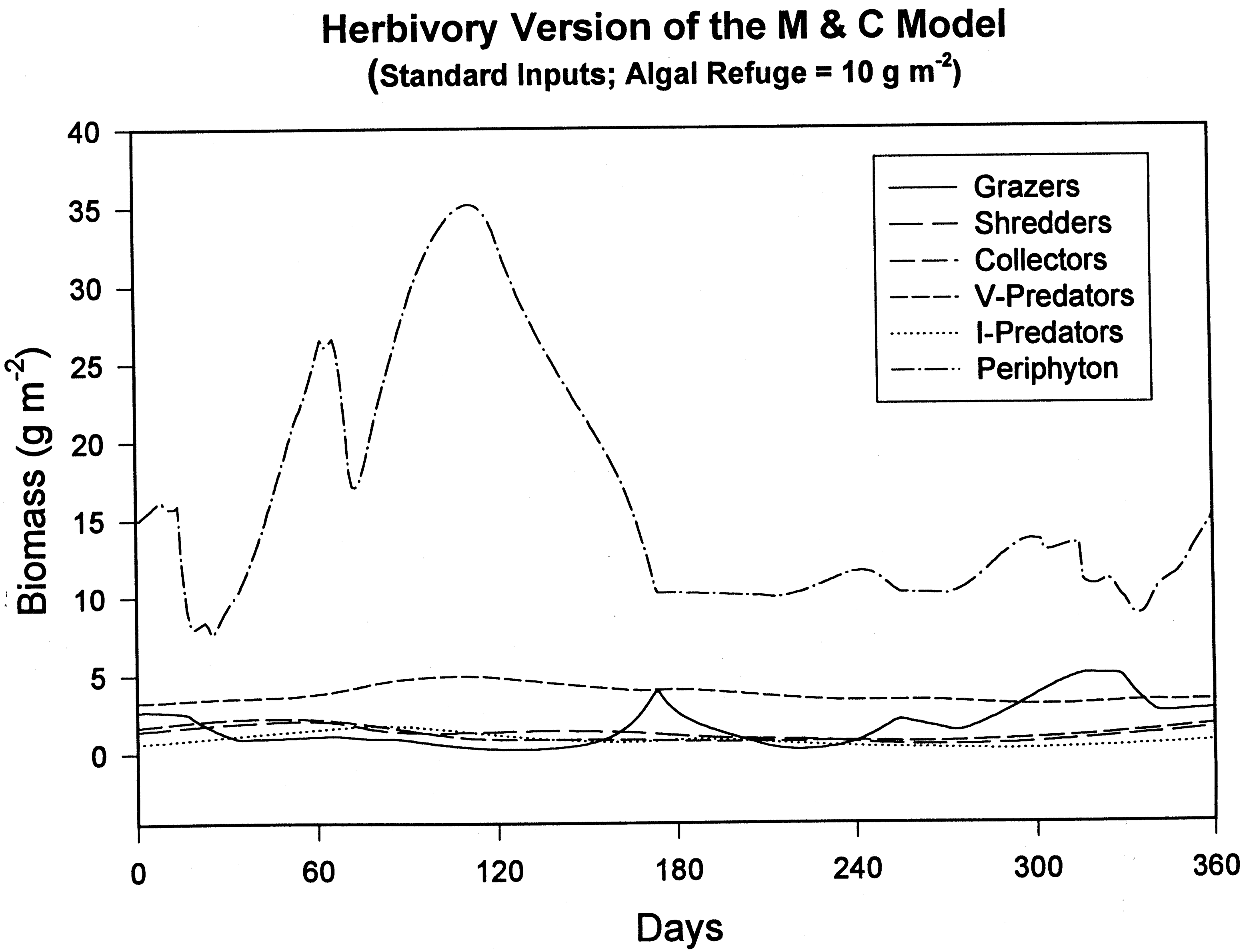


Figure 11. Seasonal dynamics of state variables representing the major biological processes in the Herbivory Version of the M & C Stream Model. The run conditions are: standard input tables; algal refuge = 10 g m^{-2}.

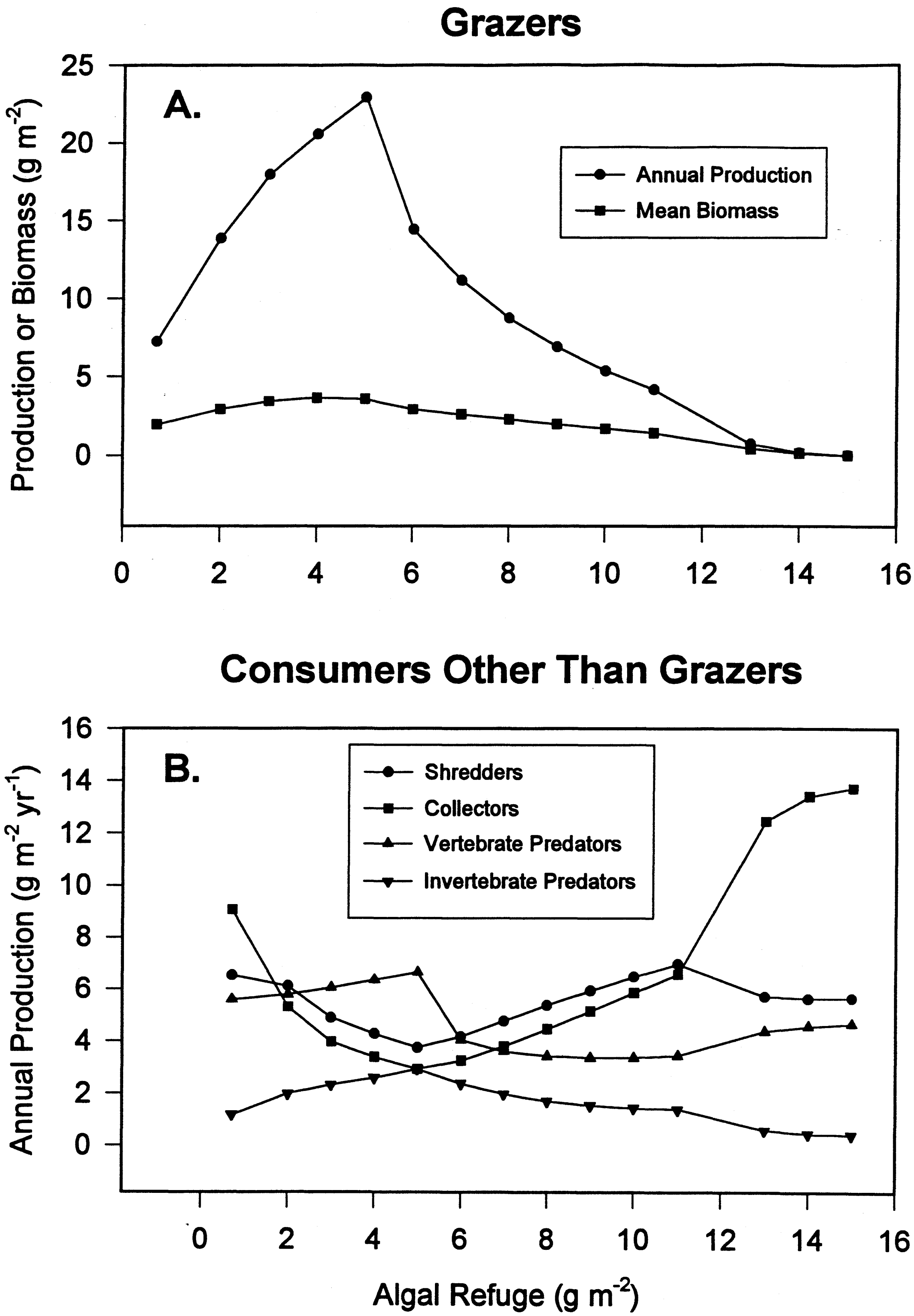


Figure 12. Relationships between annual grazer production and mean biomass and the algal refuge level (A) and between production by consumers other than grazers and the algal refuge level (B).

effects are revealed by plots of state variables (e.g., Figs. 6, 9, and 10), the corresponding energy budgets (e.g., Appendix VIII), and plots of the variables discussed on pages 26-40. For example, plots of specific growth rates for collectors at algal refuges that maximize and minimize grazer production, 5 and 14 g m^{-2}, respectively, indicate indirect effects of algal refuge on mechanisms that control the process of collecting (Fig. 13). In this case, areas between the curves in the figures predict that when grazing is low (high refuge level), the effects of predation on collectors is less and effects of food limitation are greater than when grazer production is relatively high (Fig. 12A; Fig. 13). More of such output can be obtained by making additional simulation runs while using different values for $\mathbf{b}_{72}$.

Example 2: Interaction between irradiation and food consumption

In this example, effects of irradiation on periphyton assemblages are examined in relation to factors that affect the rate of food consumption by grazers. In the Herbivory Version of the model, the rate of grazer food consumption is a function of food demand and the biomass of the periphyton assemblage.

Definition: *Food demand is the consumption rate when food is in unlimited supply and the quality of the resource is optimal.*

In the model, food demand is a function of temperature and the biomass of the consumer functional group, grazers in the case of this example. Food demand has a maximum value at 18°°C and goes to zero as the temperature approaches a low of 0° C and a high of 30° C. In natural streams, food demand also would be expected to vary with the physiological state and genetic composition of the functional group of grazers. After food demand is calculated, the model determines the realized food consumption rate by multiplying the demand by food

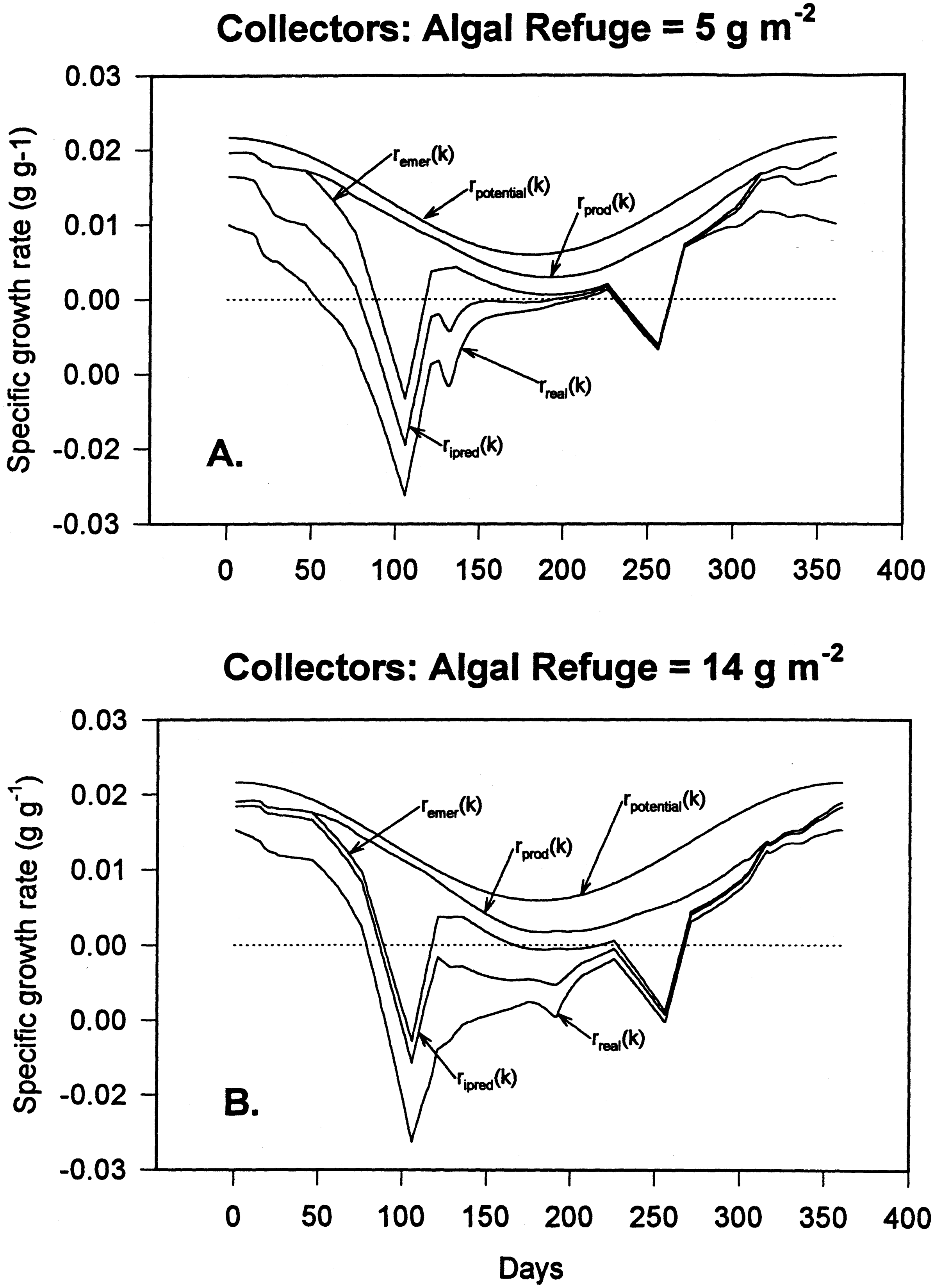


Figure 13. A set of specific growth rates for collectors generated from the Herbivory Version of the M & C Stream Model with algal refuge levels set at 5 g m^{-2} (A) and 14 g m^{-2} (B).

quality and food density limiting factors.

Definition: *The food quality limiting factor is the proportion of the demand that is allowed by the quality of the food resource.*

If the quality of the food resource is optimal, the food quality limiting factor is equal to 1, whereas if the food resource is inedible, the value is zero. The food density limiting factor also ranges from 0 to 1, and is a nonlinear function of the biomass of the food resource (see equation for g_{46} in Appendix I, page 167).

In an early version of the model, it was assumed that the food quality limiting factor had a fixed minimum value of 0.28 when the algal assemblage was 48% diatoms, 48% chlorophytes, and 4% cyanobacteria, and a maximum value of 1.00 when the assemblage was 100% diatoms. In the Herbivory Version of the model presented here (HERB.COM), the user has the option of changing the minimum value of the food quality limiting factor. This is done by setting the value of $\mathbf{b}_{121}$, a new parameter that is allowed to vary between 0.28 and 1.00. As the parameter increases in value, the effect of food quality on grazer demand decreases, and at a value of 1.0, food quality has no effect on demand. At a value of 0.28, model behavior is identical to patterns exhibited by the Standard Run (pages 44-52) and by the runs discussed in Example 1 (pages 57-66).

In this example, effects of interactions between irradiance and the grazer food consumption rate are examined by a series of simulation runs with $\mathbf{b}_{121}$ set at its standard value of 0.28. Next, the value of $\mathbf{b}_{121}$ is increased to reduce the effect of food quality, and the same simulations runs are repeated and compared to runs in which food quality has its maximum effect ($\mathbf{b}_{121}$ = 0.28). Grazer food consumption is controlled by multiplying the food demand by another parameter (**b_{100}**). In the simulation runs discussed here, **b_{100}** varies between 0.5 and 1.0, values that allows the food consumption rate to range between 50% and 100% of its standard value. Likewise, irradiation inputs also are controlled by parameters (**b_{120}** and **b_{113}**). The parameter **b_{120}** is a multiplier that adjusts the value for the irradiance reaching the bottom of the stream. For example, values for **b_{120}** equal to 0.5, 2.0, and 3.0 would generate light energy inputs equal to one-half, 2 times, and 3 times the values that are produced by the table of daily input values, EXLITE in this example. The parameter **b_{113}** allows the user to set the daily input of irradiance to a constant value. When **b_{113}** is equal to any value less than zero, the model processor will input the daily values found in EXLITE or any desired modification of this table, whereas if **b_{113}** is equal to or greater than zero, the processor treats the value of **b_{113}** as a constant daily input. For the Standard Run, **b_{113}** is equal to -1, which means that values in EXLITE are read in as the irradiation inputs.

For the first simulation run in this example, irradiation inputs are set at three times the values that are generated by EXLITE, while grazer demand and the minimum value for the food density limiting factor are the values used for the Standard Run. The commands are

C:\MODEL\HERB>**herb** (return)

CMD>**read=herb.cmd** (return)

CMD>**ib(120)=3.0** (return)

CMD>**tstop=7200** (return)

CMD>**sint=360** (return)

CMD>**sset=x(2:17)** (return)

CMD>**run** (return)

(Write down state variable values for day 7200) (return)

CMD > **reset** (return)

CMD > **tstop=360** (return)

CMD > **sint=15** (return)

CMD > **sset=x(2:7,15:17)** (return)

CMD > **ix(2:9)=3.425,1.196,1.323,3.603,.382,.893,9.745,134.286** (return)

CMD > **ix(10:17)=26.444,30.851,1.145,16.978,.668,.893,0,0** (return)

CMD > **dfile=lite3X.dmp** (return)

CMD > **dint=1** (return)

CMD > **dset=x(2:7,15:17)** (return)

CMD > **run** (return)

CMD > **q** (return)

C:\MODEL\HERB > **herbtab** (return)

CMD > **read=herbtab.cmd** (return)

CMD > **ib(120)=3.0** (return)

CMD > **ix(2:9)=3.425,1.196,1.323,3.603,.382,.893,9.745,134.286** (return)

CMD > **ix(10:17)=26.444,30.851,1.145,16.978,.668,.893,0,0** (return)

CMD > **run** (return)

CMD > **q** (return)

C:\MODEL\HERB > **budget** (return)

(Enter run title) (return)

After these commands are executed, the user will have a print file (HERB.OUT) that lists run parameters, initial state variable values, and state variable values for $\mathbf{x}_2$, $\mathbf{x}_3$, $\mathbf{x}_4$, $\mathbf{x}_5$, $\mathbf{x}_6$, $\mathbf{x}_7$, $\mathbf{x}_{15}$, $\mathbf{x}_{16}$, and $\mathbf{x}_{17}$ at a time interval of 15 days; a dump file entitled LITE3X.DMP that can be use for plotting state variables; and a file entitled STREAM.TAB that represents an annual energy budget for the run. All three of these output files are stored on the MODEL\HERB subdirectory unless otherwise specified on the command file (HERB.CMD) or by a command from the FLEX model processor during the run.

At this point, it is suggested that the user make two more simulation runs, one at 2 times the irradiation inputs generated by EXLITE, and the other at a constant daily input of 2500 ft-c. This is accomplished in the first run by setting $\mathbf{b}_{120}$ to a value of 2.0 to change inputs to 2 times the standard table values, and in the second run by setting $\mathbf{b}_{113}$ to a value of 2500. Also remember that in the second run, $\mathbf{b}_{120}$ is not changed, i.e., it is allowed to remain at its standard value of 1.0 which is introduced in the command file (HERB.CMD) by the **read** command.

To continue the study, the next series of runs will repeat the manipulations of the light schedule while varying the rate of grazer food consumption. In this series of simulations, commands for the run at 90% of the standard grazer food demand and 2 times the standard irradiation are

C:\MODEL\HERB>**herb** (return)

CMD>**read=herb.cmd** (return)

CMD>**ib(120)=2.0** (return)

CMD>**ib(100)=0.9** (return)

CMD>**tstop=7200** (return)

CMD>**sint=360** (return)

CMD>**sset=x(2:17)** (return)

CMD>**run** (return)

(Write down state variable values for day 7200) (return)

CMD>**reset** (return)

CMD>**tstop=360** (return)

CMD>**sint=15** (return)

CMD>**sset=x(2:7,15:17)** (return)

CMD>**ix(2:9)=3.254,1.041,1.083,3.987,.818,.892,9.184,142.717** (return)

CMD>**ix(10:14)=27.865,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=.892,3.378E-7,5.36E-7** (return)

CMD>**dfile=I2Xd90.dmp** (return)

CMD>**dint=1** (return)

CMD>**dset=x(2:7,15:17)** (return)

CMD>**run** (return)

CMD>**q** (return)

C:\MODEL\HERB>**herbtab** (return)

CMD>**read=herbtab.cmd** (return)

CMD>**ib(120)=2.0** (return)

CMD>**ib(100)=0.9** (return)

CMD>**ix(2:9)=3.254,1.041,1.083,3.987,.818,.892,9.184,142.717** (return)

CMD>**ix(10:14)=27.865,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=.892,3.378E-7,5.36E-7** (return)

CMD>**run** (return)

CMD>**q** (return)

C:\MODEL\HERB>**budget** (return)

(Enter run title) (return)

To complete a study, the user can continue to make simulation runs while using parameter values that follow a pattern consistent with the objective questions under consideration. For the objectives of this example, the desired model output is obtained by the simulation runs listed in Table 3. For the first set of 20 runs, the minimum value for the food quality limiting factor is set at 0.28, its standard value. The minimum value is increased to 0.80 for the second set of 20 runs, a change that greatly decreases the negative effect of poor food quality on the rate of grazer food consumption. To obtain the desired output from the runs listed in Table 3, only 13 simulation runs (instead of 20) are required when $\mathbf{b}_{121}$ is set at 0.28, because in some cases, runs with the same irradiation inputs have identical output when the system does not support grazing (i.e., grazer biomass remains at zero with a particular set of parameter values). When $\mathbf{b}_{121}$ is set at 0.80, there are only two identical runs, and 19 runs are required to complete the set.

In the 40 simulation runs required to complete the study listed in Table 3, the user will encounter 5 runs in which system dynamics operates on a two-year cycle rather than a one-year cycle. The runs that exhibit this behavior are 2 and 5 at $\mathbf{b}_{121}$ equal to 0.28 and 2, 5, and 9 at $\mathbf{b}_{121}$ equal to 0.8. When cycles greater than one year occur, several modifications in

Table 3. A list of proposed simulation runs for the investigation of the interaction between irradiation and grazer food consumption in relation to the quality of the periphyton food resource.

Run No.	b_{120}	b_{113}	b_{100}	b_{121} (set 1)	b_{121} (set 2)
1	1.0	-1	1.00	0.28	0.80
2	2.0	-1	1.00	0.28	0.80
3	3.0	-1	1.00	0.28	0.80
4	1.0	2500	1.00	0.28	0.80
5	1.0	-1	0.90	0.28	0.80
6	2.0	-1	0.90	0.28	0.80
7	3.0	-1	0.90	0.28	0.80
8***	1.0	2500	0.90	0.28	0.80
9	1.0	-1	0.75	0.28	0.80
10*	2.0	-1	0.75	0.28	0.80
11**	3.0	-1	0.75	0.28	0.80
12***	1.0	2500	0.75	0.28	0.80
13	1.0	-1	0.60	0.28	0.80
14*	2.0	-1	0.60	0.28	0.80
15**	3.0	-1	0.60	0.28	0.80
16***	1.0	2500	0.60	0.28	0.80
17	1.0	-1	0.50	0.28	0.80
18*	2.0	-1	0.50	0.28	0.80
19**	3.0	-1	0.50	0.28	0.80
20***	1.0	2500	0.50	0.28	0.80

* Runs 10, 14, and 18 are identical when b_{121} is equal to 0.28
** Runs 11, 15, and 19 are identical when b_{121} is equal to 0.28
*** Runs 8, 12, 16, and 20 are identical when b_{121} is equal to 0.28

the run procedure outlined above are required. For example, the commands for run 5 at $\mathbf{b}_{121}$ equal 0.8 are

C:\MODEL\HERB>**herb** (return)

CMD>**read=herb.cmd** (return)

CMD>**ib(100)=0.9** (return)

CMD>**ib(121)=0.8** (return)

CMD>**tstop=7200** (return)

CMD>**sint=360** (return)

CMD>**sset=x(2:17)** (return)

CMD>**run** (return)

At the conclusion of the simulation, the user will notice that the state variables return to their initial values after 720 days (2 years) instead of the annual cycle of 360 days.
(Write down state variable values for day 7200) (return)

CMD>**reset** (return)

CMD>**tstop=720** (return)

CMD>**sint=15** (return)

CMD>**sset=x(2:7,15:17)** (return)

CMD>**ix(2:9)=2.826,1.557,2.257,5.373,.214,.824,11.928,108.428** (return)

CMD>**ix(10:14)=21.962,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=.824,2.732E-4,6.055E-24** (return)

CMD>**dfile=b1b9b8.dmp** (return)

CMD>**dint=1** (return)

CMD > **dset=x(2:7,15:17)** (return)

CMD > **run** (return)

CMD > **q** (return)

C:\MODEL\HERB > **herbtab** (return)

CMD > **read=herbtab.cmd** (return)

CMD > **ib(100)=0.9** (return)

CMD > **ib(121)=0.8** (return)

CMD > **tstop=720** (return)

CMD > **ix(2:9)=2.826,1.557,2.257,5.373,.214,.824,11.928,108.428** (return)

CMD > **ix(10:14)=21.962,30.851,1.145,16.978,.668** (return)

CMD > **ix(15:17)=.824,2.732E-4,6.055E-24** (return)

CMD > **run** (return)

CMD > **q** (return)

C:\MODEL\HERB > **bud2yr** (return)

(Enter run title) (return)

In this run, notice that the simulation time period must correspond to the length of the cycle, in this case 720 days (2 years), and that the program that generates an energy budget for a two-year simulation period is BUD2YR.COM. The HERB subdirectory on the enclosed diskette has four programs that generate energy budgets for time periods of 1, 2, 3, and 4 years: BUDGET.COM, BUD2YR.COM, BUD3YR.COM, and BUD4YR.COM, respectively. If the user needs an annual average value for production estimates from BUD2YR.COM, BUD3YR.COM, or BUD4YR.COM, it is necessary to divide each value by the number of years that the program represents.

Some of the output for the 40 simulation runs proposed in Table 3 is presented in Figures 14, 15, 16, and 17. This output is based on information from BUDGET.COM and BUD2YR.COM and represents annual production rates for the six major biological processes represented by the model (grazing, shredding, collecting, vertebrate predation, invertebrate predation, and primary production).

When the minimum value for the food quality limiting factor is 0.28, the model predicts that grazer production is maximized and shredder and collector production is minimized when grazer food demand is equal to the standard value (100%) and irradiation input is at its maximum constant value of 2500 ft-c (Fig. 14A,B,C). Mechanisms that account for these patterns relate to the responses of vertebrate and invertebrate predators to changes in grazer production (Fig. 15A,B). When grazer production is relatively high, predator production also is high, which in turn, puts more predator pressure on shredders and collectors. When grazer food demand decreases to 75% and 60%, the process of grazing can only continue with the standard table of irradiation inputs (1X), because the higher irradiation levels reduce the quality of the periphyton food resource by increasing the abundance of chlorophytes and cyanobacteria. The model also indicates that the processes of vertebrate and invertebrate predation are more tightly coupled to the process of grazing than to the processes of shredding or collecting, because grazer assimilation efficiency (0.55) is higher than either shredder or collector assimilation efficiency (0.18 and 0.21, respectively). If the user wants to explore model behavior further relative to changes in assimilation efficiency for these processes, the parameters $\mathbf{b_{92}}$, $\mathbf{b_{93}}$, and $\mathbf{b_{94}}$ can be used to set the assimilation ratios to the

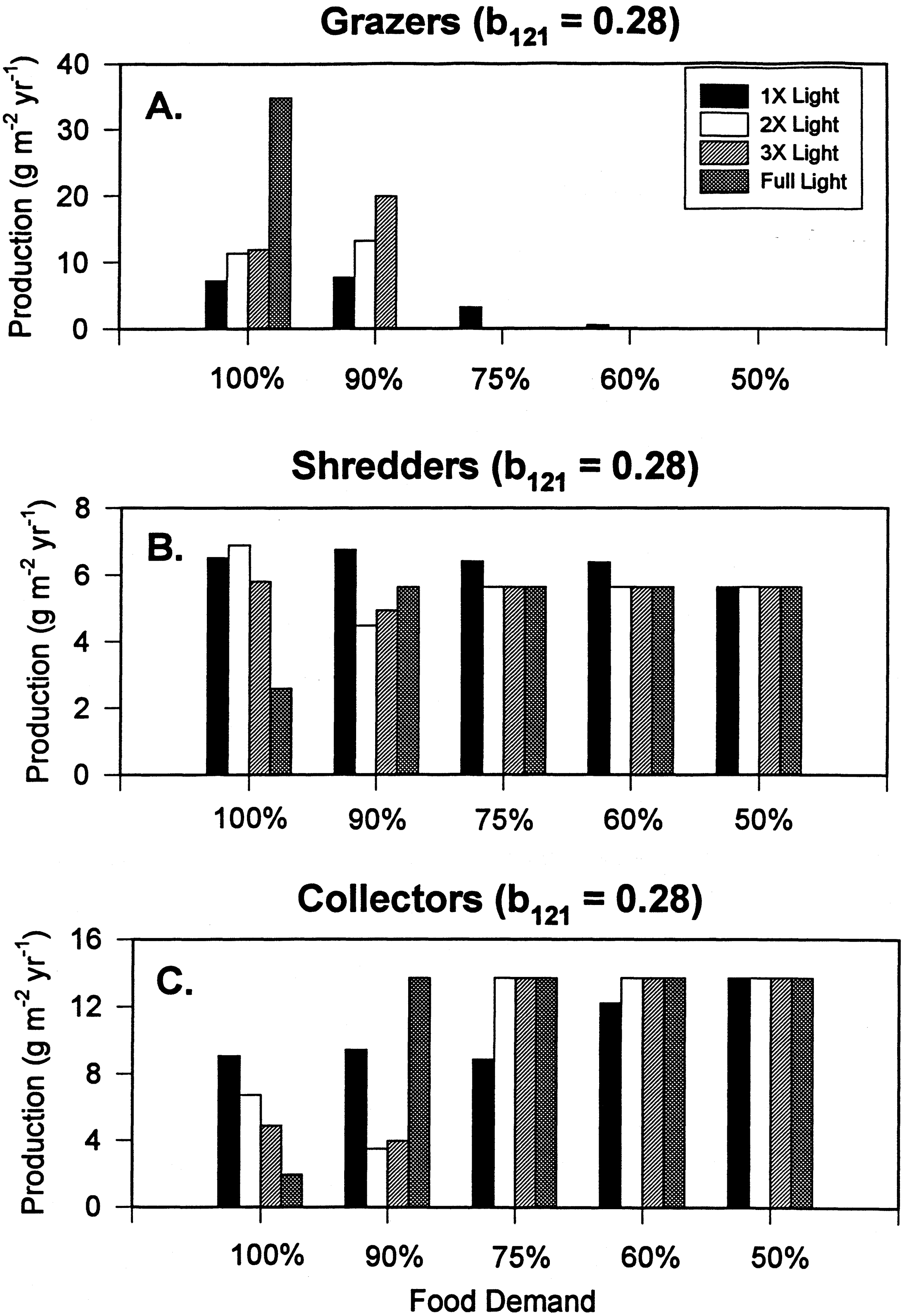


Figure 14. Relationships between grazer (A), shredder (B), and collector (C) production and food demand at four levels of irradiation and the food quality parameter ($\mathbf{b_{121}}$) equal to 0.28.

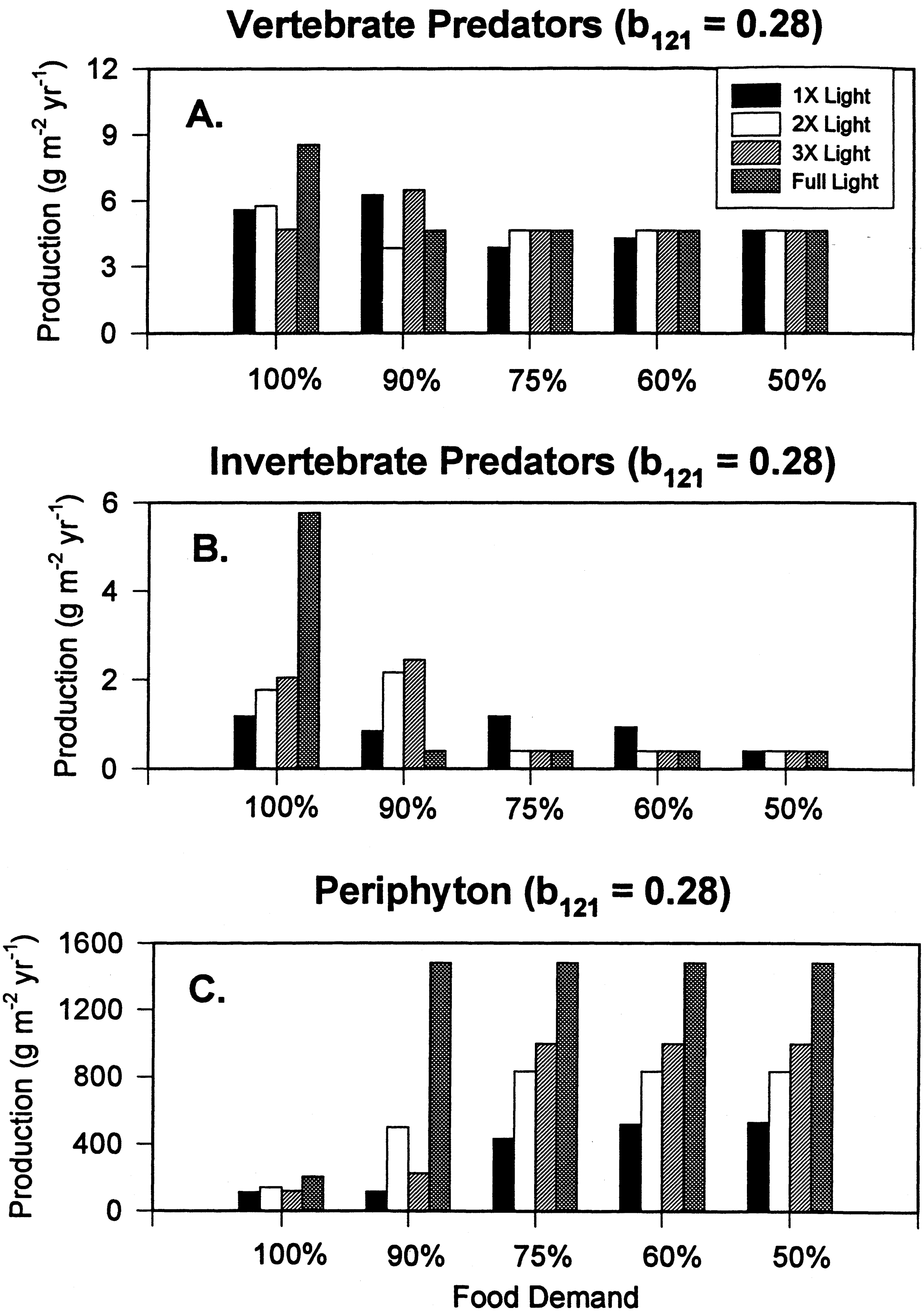


Figure 15. Relationships between vertebrate predator (A), invertebrate predator (B), and periphyton (C) production and food demand at four levels of irradiation and the food quality parameter (**b_{121}**) equal to 0.28.

desired values (Appendix I, page 191).

When the negative effects of food quality are reduced by increasing the minimum value for the food quality limiting factor to 0.8, grazer production is maximized when light energy inputs are at a maximum and grazer food demand is 90% of the standard value (Fig. 16A). In general, the reduction of the negative effects of food quality corresponds to higher rates of grazer production when food demand is less than the standard value, and corresponding lower rates of shredder and collector production (Fig. 16A,B,C). Again, these patterns relate to the direct and indirect effects of predation on the primary consumer functional groups (grazers, shredders, and collectors). When model inputs do not support the process of grazing (i.e., the grazer biomass remains at a zero value), the other consumer processes are uncoupled from the process of primary production (Figs 15C and 17C) and assume constant values independent of irradiation inputs (Figs. 14B,C; 15A,B; 16B,C; 17A,B).

The kind of output generated by the series of runs described in this example is complex and requires considerable study to obtain an understanding of mechanisms predicted by model behavior. In addition to the graphs illustrated in Figures 14-17, the user can plot state variables for various runs, study and plot some of the other variables in the energy budget tables, and if mechanisms are still unclear, generate and plot specific growth rates for some of the runs (see pages 26-40). Of course, as the number of parameters under investigation increases in a series of runs, output becomes more complex and interpretation is more challenging and time consuming.

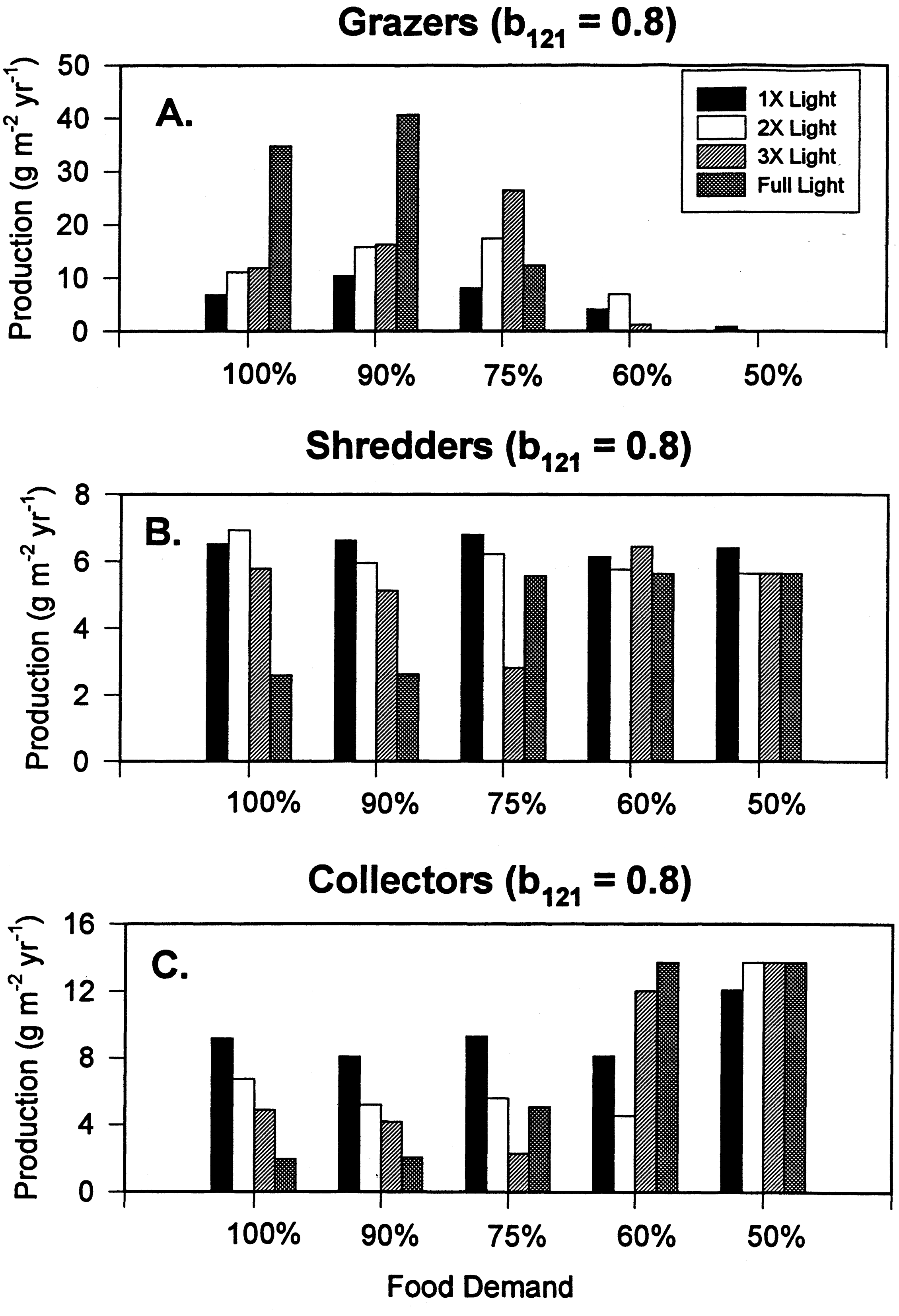


Figure 16. Relationships between grazer (A), shredder (B), and collector (C) production and food demand at four levels of irradiation and the food quality parameter (b_{121}) equal to 0.8.

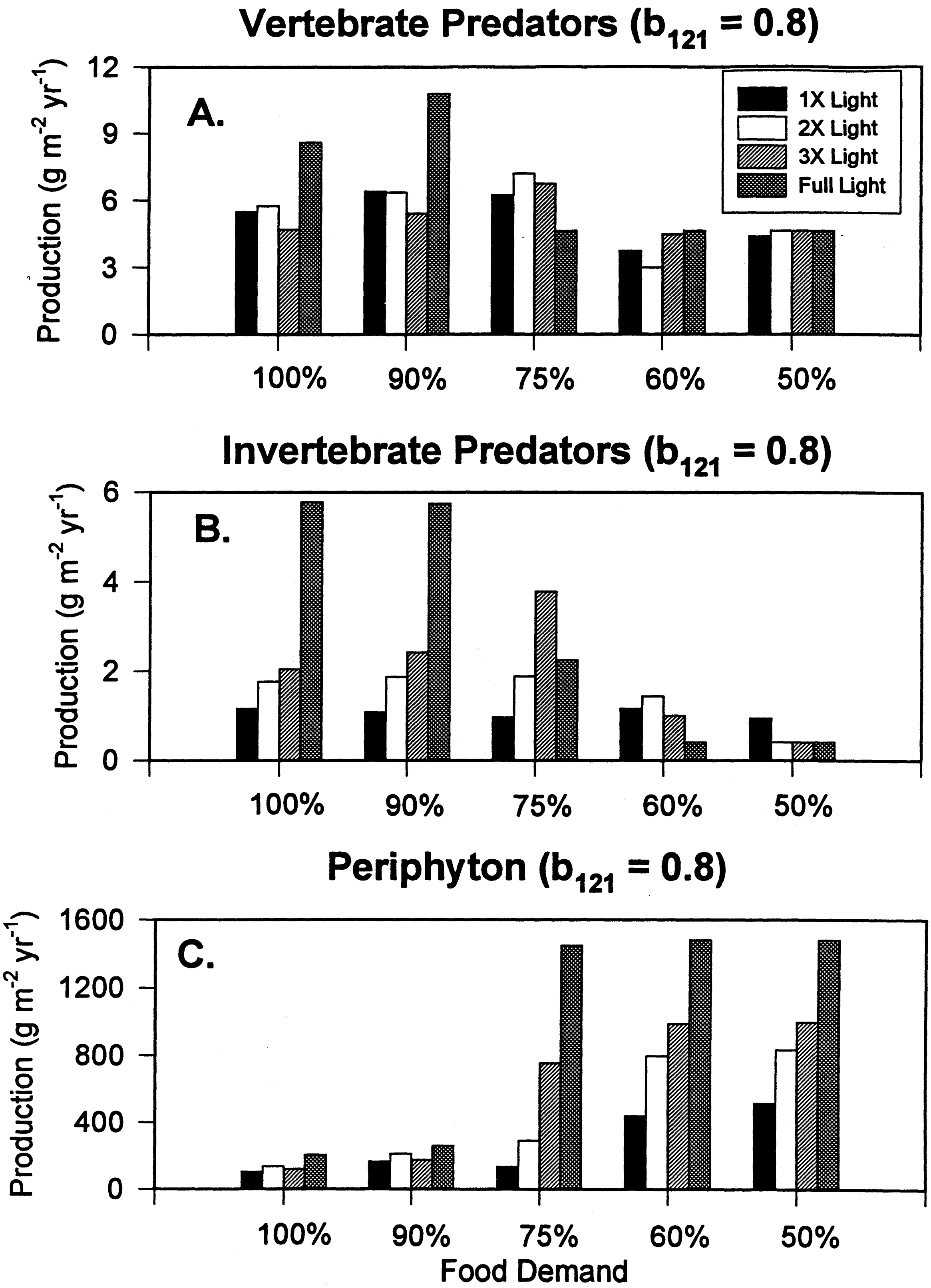


Figure 17. Relationships between vertebrate predator (A), invertebrate predator (B), and periphyton (C) production and food demand at four levels of irradiation and the food quality parameter (b_{121}) equal to 0.8.

Example 3: Effects of a limiting nutrient when light energy is not limiting

The simulations in this example are designed to investigate effects of a limiting nutrient at high inputs of irradiation (i.e., when light energy is usually not a limiting factor). Such conditions are more typical of larger, unshaded rivers than of smaller, lower order streams. In this study, it is assumed that the limiting nutrient is nitrate nitrogen, which is often the case in Western Oregon, and the range of concentrations of interest is between 0.01 and 0.5 mg l^{-1}. Schedules of allochthonous and irradiation inputs are derived from data for the Willamette River (Oregon). Irradiance for these simulations reaches its highest mean daily value of 2000 ft-c during the summer months, whereas annual allochthonous input is 210 g m^{-2}. In this case, approximately 75% of the detrital inputs are introduced at a time corresponding to a period from the beginning of September to the end of December. Temporal patterns for these variables during all simulation runs in this example are plotted in Figures 18A and 18B.

Simulation runs described in this example involve the manipulation of two parameters, $\mathbf{b}_{111}$ which sets the nitrate level to a constant concentration, and $\mathbf{b}_{121}$, the minimum value for the food quality limiting factor discussed in Example 2. Example 2 demonstrated that the effect of food quality on the process of grazing becomes more pronounced as irradiation inputs increase, because the corresponding increase in primary productivity produces changes in the taxonomic composition of the periphyton food resource. Therefore, the $\mathbf{b}_{121}$ parameter is changed in combination with the nutrient parameter ($\mathbf{b}_{111}$) in order to investigate model behavior when light energy is not limiting and the potential effect of food quality is at a maximum when other inputs favor high rates of primary production. The proposed set of simulation runs are listed in Table 4. For this set, there are seven nitrate concentrations (0.01,

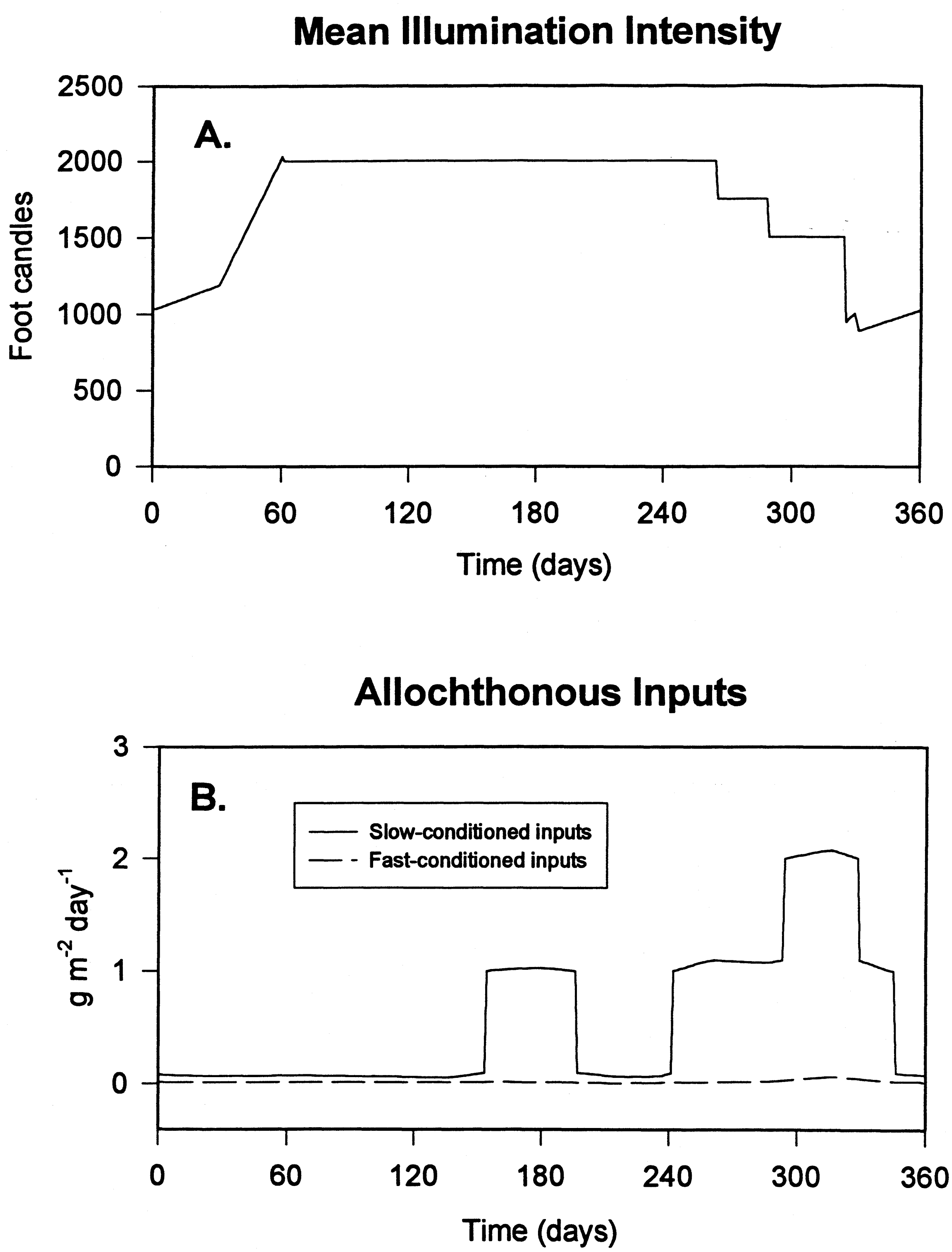


Figure 18. Irradiation (A) and allochthonous (B) schedules for Example 3 of the Herbivory Version of the M & C Stream Model. Data are based on measurements for the Willamette River (see text).

0.03, 0.05, 0.07, 0.1, 0.3, and 0.5 mg l^{-1}) and six values for $\mathbf{b_{121}}$ (1.0, 0.9, 0.8, 0.7, 0.6, and 0.5) for a total of 42 runs.

Table 4. A list of proposed simulation runs for the investigation of the effects of a limiting nutrient at a high input of irradiation. Runs 1 - 7 are repeated six times, each with a different value for b_{121}, for a total of 42 simulations.

Run No.	b_{111}	b_{121} (1)	b_{121} (2)	b_{121} (3)	b_{121} (4)	b_{121} (5)	b_{121} (6)
1	0.01	1.0	0.9	0.8	0.7	0.6	0.5
2	0.03	1.0	0.9	0.8	0.7	0.6	0.5
3	0.05	1.0	0.9	0.8	0.7	0.6	0.5
4	0.07	1.0	0.9	0.8	0.7	0.6	0.5
5	0.10	1.0	0.9	0.8	0.7	0.6	0.5
6	0.30	1.0	0.9	0.8	0.7	0.6	0.5
7	0.50	1.0	0.9	0.8	0.7	0.6	0.5

An example of the commands for one of the simulation runs listed in Table 4, in this case run No. 4 with a minimum value of the food quality limiting factor set at 0.9, is listed below:

C:\MODEL\HERB> **edit herb.cmd** (return)

At this point, the user must change the name of three input tables in the command file. The table names EXLITE, SALLOC, *and* FALLOC *are changed to* LITE2000, WRSALOC, *and* WRFALOC, *respectively. These changes can be made in the DOS editor or in any other system that edits and outputs* ASCII *files. If an energy budget is desired for this run, the user must also edit* HERBTAB.CMD, *the command file for* HERBTAB.COM. *After these changes are made, exit the editor and type*

C:\MODEL\HERB > **herb** (return)

CMD > **read=herb.cmd** (return)

CMD > **ib(111)=0.07** (return)

CMD > **ib(121)=0.9** (return)

CMD > **tstop=7200** (return)

CMD > **sint=360** (return)

CMD > **sset=x(2:17)** (return)

CMD > **run** (return)

(Write down state variable values for day 7200) (return)

Note: The user will notice during the run that the system is operating on a 4-year cycle instead of a 1-year cycle. If you are uncertain about whether or not the system has reached a steady state, simply **reset** *the system, extend the simulation period by the* **tstop** *command (say for 14400 days or forty years), and repeat the run listed above. After writing down state variable values for day 7200, continue by typing*

CMD > **reset** (return)

CMD > **tstop=1440** (return)

CMD > **sint=15** (return)

CMD > **sset=x(2:7,15:17)** (return)

CMD > **ix(2:9)=2.964,.567,.57,29.925,.366,1.978,6.035,91.619** (return)

CMD > **ix(10:14)=2.642,14.527,.114,4.847,6.681E-2** (return)

CMD > **ix(15:17)=1.978,0,1.199E-57** (return)

CMD > **dfile=nit07fq9.dmp** (return)

CMD > **dint=1** (return)

CMD > **dset=x(2:7,15:17)**	(return)
CMD > **run**	(return)
CMD > **q**	(return)
C:\MODEL\HERB > **herbtab**	(return)
CMD > **read=herbtab.cmd**	(return)
CMD > **tstop=1440**	(return)
CMD > **ib(111)=0.07**	(return)
CMD > **ib(121)=0.9**	(return)
CMD > **ix(2:9)=2.964,.567,.57,29.925,.366,1.978,6.035,91.619**	(return)
CMD > **ix(10:14)=2.642,14.527,.114,4.847,6.681E-2**	(return)
CMD > **ix(15:17)=1.978,0,1.199E-57**	(return)
CMD > **run**	(return)
CMD > **q**	(return)
C:\MODEL\HERB > **bud4yr**	(return)
(Enter run title)	(return)

The commands listed above will generate the usual output that the user needs to interpret the results, namely a print file (HERB.OUT), a dump file that can be used to plot state variables (NIT07FQ9.DMP), and an energy budget file (STREAM.TAB) that provides tables based on a simulation period of four years. Annual production rates for the six major biological processes represented by the model and derived from the 42 simulation runs listed in Table 4 are plotted Figures 19 and 20. Other aspects of the output from these runs (e.g., state variable seasonal dynamics, annual mean biomass for functional groups of organisms, and patterns of energy loss) also can be plotted or tabulated, depending on the objective questions under consideration.

If irradiance is not limiting photosynthesis, the model predicts that the dynamics of the algal assemblage is particularly sensitive to the availability of a limiting nutrient, and that primary and secondary consumers are indirectly affected by nutrient changes, in this case, especially when the nitrate concentration is below 0.1 mg l^{-1} (Figs. 19A,B,C and 20A,B). At a nitrate concentration of 0.03 mg l^{-1} or less, grazers are able to persist in the system when the food quality parameter is low (< 0.6) because the algal biomass and primary production are never high enough to allow the growth of chlorophytes (Fig. 20C). In other words, when nutrient supply is low, food quality remains high regardless of the value of the parameter, because diatoms dominate the assemblage at low biomasses. At nitrate concentrations of 0.07 mg l^{-1} or greater, grazer production is much more sensitive to changes in the food quality limiting factor. A threshold response value for the food quality parameter is between 0.7 and 0.8. From an ecological perspective, this means that when grazer food demand can be reduced to 70% of the maximum or below by changes in food quality, grazer production actually decreases when increases in nutrient supply and primary production bring about corresponding increases in the proportional abundances of taxa that decrease food quality. In the model, these taxa are chlorophytes and cyanophytes. When the effect of food quality is minimal (i.e., the food quality parameter is 0.8 or greater), grazer production increases or is relatively unaffected when nitrate concentration increases to values above 0.07 mg l^{-1}.

The model predicts that shredders, collectors, and predators have different responses to changes in nitrate concentration and the food quality limiting factor. The response of

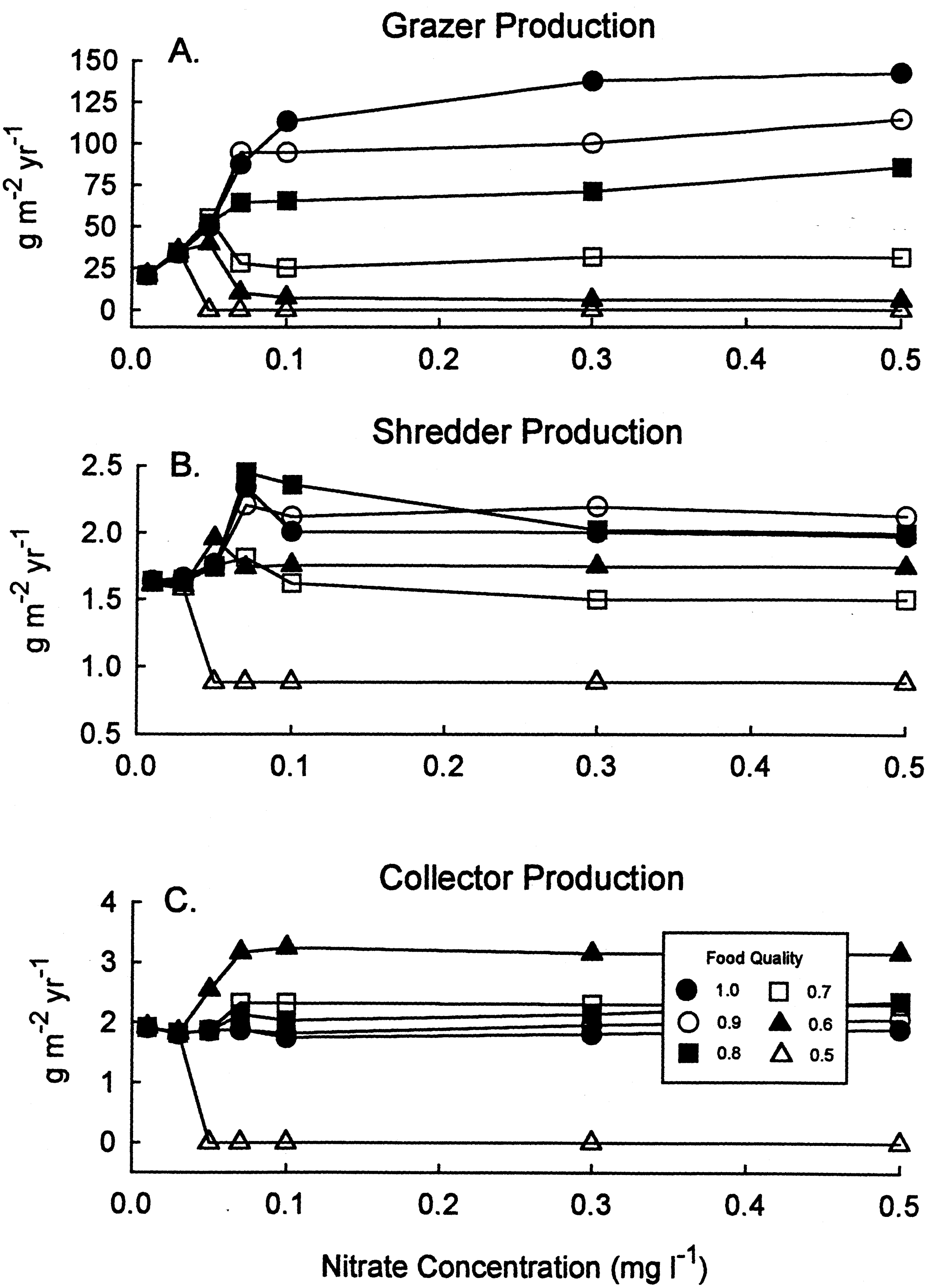


Figure 19. Relationships between annual grazer (A), shredder (B), and collector (C) production and nitrate concentration at different levels of food quality.

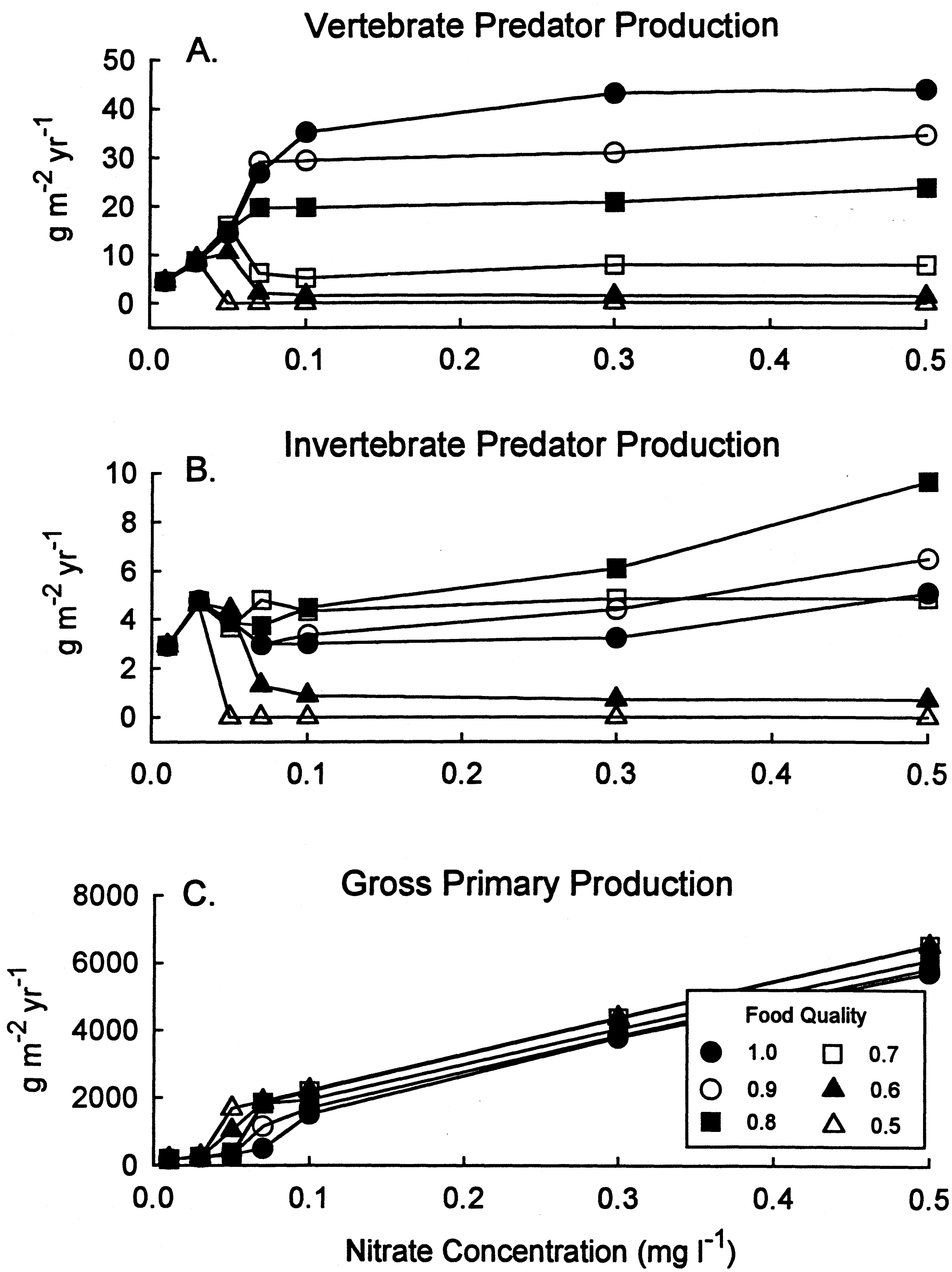


Figure 20. Relationships between annual vertebrate predator (A), invertebrate predator (B), and gross primary (C) production and nitrate concentration at different levels of food quality.

vertebrate predators is similar to the pattern exhibited by the grazers, indicating that these functional groups are tightly coupled bioenergetically (Figs. 19A and 20A). With a relatively high nitrate concentration (0.1 mg l^{-1} or greater), invertebrate predators reach maximum production when the food quality parameter is 0.8 (Fig. 20B), a pattern that is a manifestation of the trade-offs between availability of food resources (grazer, shredder, and collector biomasses) and biomass losses to vertebrate predators. At nitrate concentrations of 0.07 mg l^{-1} and greater, collector production is inversely related to the food quality parameter except when grazer production is zero ($\mathbf{b}_{121}$ = 0.5). This pattern suggests that the process of collecting is controlled by vertebrate predation and becomes resource limited only when the process of grazing fails to produce enough detrital particles. In reality, there are other sources of fine particulate organic matter in natural streams, and the process of collecting is probably not as tightly coupled to the processes of grazing and shredding as the model suggests. The relationship between shredder production and the food quality limiting factor is complex (Fig. 19B) and is directly related to the seasonal pattern of allochthonous inputs and indirectly related to the response of the functional groups of predators to changes in grazer biomass. However, for any given value of $\mathbf{b}_{121}$, shredder production and collector production are relatively unaffected by changes in nitrate supply when concentrations are above 0.07 mg l^{-1}.

Other Output Options

The FLEX model processor allows the user to output any x, z, g, or y variable during each simulation run. These symbols correspond to the state, input, interaction (intermediate), and output variables, respectively, and are defined and discussed in Appendix I, page 147-149. Output of any of these varaibles can be assigned to the screen by the sset command, the print file by the **pset** command, or the dump file by the **dset** command. For the examples in the earlier sections of this tutorial, output was confined to state variables (*x*) or the special *y* variables that aid in the interpretation of state variable dynamics. However, for interpretative purposes or for aid in presentation of simulation results, it is sometimes helpful to include selected input (*z*) or interaction (*g*) variables in the output. For example, to generate files necessary for plots of the irradiance and allochthonous schedules for the Standard Run of Version I of the model (Figure 2A,B, page 9), type

C:\MODEL\HERB > **cd\model\stand**	(return)
C:\MODEL\STAND > **stream**	(return)
CMD > **read=stream.cmd**	(return)
CMD > **dfile=litelpom.txt**	(return)
CMD > **dint=1**	(return)
CMD > **dset=z(2,5:6)**	(return)
CMD > **run**	(return)

These commands will produce a dump file (LITELPOM.TXT) that will list the 360 values found in each of the following input tables: EXLITE, SALLOC, and FALLOC (Appendix II, pages 193-194, 196-198). These tables are introduced by the variables $\mathbf{z_2}$, $\mathbf{z_5}$, and $\mathbf{z_6}$ and represent irradiation inputs and inputs of slow-conditioned and fast-conditioned allochthonous material, respectively (Appendix I, page 150). The dump file LITELPOM.TXT can be imported into any plotting program to produce graphs similar to Figures 2A and 2B.

To produce output of variables other than those introduced in earlier sections of this tutorial, the user will need to become more familiar with the mathematical structure of the model version of interest. Complete mathematical documentation of the three versions of the model can be found in Appendix I (Version I), Appendix V (Herbivory Version), and Appendix IX (Riparian Version).

As another example, assume that the user is interested in examining food consumption rates by primary consumers during a Standard Run of Version I of the model. In this case, the user needs to know which variables correspond to the consumption of periphyton by grazers, the consumption of LPOM by shredders, and the consumption of FPOM by collectors. A study of the mathematical documentation of Version I of the model reveals that these food consumption rates are expressed mathematically by variables $\mathbf{g_{51}}$, $\mathbf{g_{52}}$, and $\mathbf{g_{53}}$ (Appendix I, page 168). Therefore, commands for the desired simulation run are

C:\MODEL\STAND>**stream**	(return)
CMD>**read=stream.cmd**	(return)
CMD>**dfile=consume.txt**	(return)
CMD>**dint=1**	(return)
CMD>**dset=g(51:53)**	(return)
CMD>**sset=g(51:53)**	(return)
CMD>**run**	(return)

In this case, the **sset** command also is included to illustrate that the *g* variables can be monitored on the screen during the simulation run when desired. Likewise, these variables also can be listed in the print file by including the **pset= g(51:53)** command.

THE M & C STREAM MODEL: RIPARIAN VERSION

Introduction

For Version I and the Herbivory Version of the M & C Stream Model, light energy inputs are introduced by a table of illumination values (ft-c) at a time resolution of one day. Therefore, each value in the table represents an equivalent mean effect of light on the daily rate of primary production. In contrast, the Riparian Version of the model allows the user to introduce a table of irradiation inputs at an hourly level of resolution, a feature that is useful when a more extensive set of light measurements is available for study. In particular, this version of the model is useful for the investigation of effects of riparian zone canopy structure on process dynamics in low-order streams. In the Riparian Version, it is assumed that the maximum day length is 16 hours and, as with Version I and the Herbivory Version, the length of the year is 360 days (i. e., 12 30-day months). Consequently, the table of light energy inputs required to run the Riparian Version of the model is considerably larger than EXLITE (Appendix II), consisting of 360 rows (1 row for each day) and 16 columns (one column for each daylight hour of each day).

Parameterization of early versions of the model was based on experiments during which light was measured in illumination units (foot-candles). For the Riparian Version of the model, the current convention of $\mu mol\ quanta\ m^{-2}\ s^{-1}$ is used as the unit of irradiation for the input table of hourly values. If the user is uncomfortable with the illumination unit used in Version I and the Herbivory Version of the model, a rough approximation of foot-candle values from light quanta data is

$$ft\text{-}c = \frac{(\mu mol\ quanta\ m^{-2}\ s^{-1})}{0.2} .$$

Whereas this conversion is too crude for most research purposes, it is close enough to generate new tables for Version I and the Herbivory Version of the model.

The Riparian Version of the M & C Stream Model is an example of a two-level model in which the rate of primary production is calculated at an hourly time resolution, in response to the expanded table of irradiation inputs, and the rest of the system runs at a daily time resolution, similar in structure to Version I and the Herbivory Version of the model. This level of complexity is facilitated by the FLEX model processor, which can run models with up to 5 different levels of temporal resolution. The Riparian Version of the model represents a modification of the Herbivory Version with the added feature that photosynthesis and partitioning of primary production among the three algal functional groups (diatoms, cyanobacteria, and chlorophytes) are modeled at an hourly resolution instead of a temporal resolution of one day. In comparison to the Herbivory Version, the Riparian Version requires more computer time to complete a simulation run, but with the speed of the newer PC machines (486 and Pentium processors), the increase in run time is insignificant for most purposes.

In the description of the structure and use of the Riparian Version of the model that follows this introduction, it is assumed that the user is familiar with Version I, the Herbivory Version, and the earlier sections of this tutorial. A brief outline of the technical details of the Riparian Version concentrates on that part of model structure that is concerned with the hourly level of resolution and the manner in which information is exchanged between the two resolution levels, aspects that are different from the Herbivory Version. After the technical section, the command file and corresponding simulation procedures are described along with an example that will expose the user to some of the properties of the model.

Technical Details of a 2-Level Model

Level 1 of the Riparian Version of the model runs at a time resolution of one day and contains many of the same variables, functions, and parameters that are found in the Herbivory Version. Level 2 of the Riparian Version runs at a resolution of one hour for 16 hours, the assumed maximum daylength during a 360-day year. Level 2 contains all variables and functions concerned with the calculation of primary production and the partitioning of that production among the functional groups of algae. All energy losses related to the Primary Production subsystem (Fig. 1) are obtained from variables and functions in Level 1 at a time resolution of one day.

To set up a 2-level model according to the FLEX convention, the programmer defines the *x* (state), *g* (intermediate), *f* (update increment), and *y* (output) variables and *b* parameters for each level (see Appendix I, pages 147-148), and writes the corresponding equations that express system dynamics at the two levels of temporal resolution. The two resolution levels then are coupled together by the FLEX model processor during each simulation run. The steps required for coupling the two levels of resolution are:

1. Variables in Level 1 that are required for functions in Level 2 are set equal to a special set of *g* variables, referred to here as coupling variables.
2. During each iteration, the coupling variables are passed down to Level 2 and treated as parameters (constants) at that level. In other words, the programmer specifies a Level 2 *b*

value for each of the coupling variables past down from Level 1.

3. After the completion of the desired number of iterations at Level 2, information is past back up to Level 1 by setting the variables generated in Level 2 that are needed in Level 1 equal to a set of output variables (*y* variables).

4. The output variables generated in Level 2 then are passed up to Level 1 and made equal to another set of *g* variables, variables that can then be used for functions in Level 1.

This coupling procedure as applied to the Riparian Version of the model is diagrammed in Figure 21.

In the Riparian Version of the model there are seven variables generated in Level 1 that are also needed in Level 2 for the calculation of primary production. These variables include stream depth (**z[10]**), suspended load (**z[7]**), nutrient concentration (**z[3]**), periphyton biomass (**x[7]**), water temperature (**z[1]**), current velocity effect on primary production (**z[14]**), and leakage of dissolved organic matter from periphyton biomass (**g[59]**). In Level 1, these variables are set equal to the coupling variables **g[75]**, **g[76]**, **g[77]**, **g[78]**, **g[79]**, **g[80]** and **g[81]**, respectively (Fig. 21). The coupling variables are passed down to Level 2 and become the parameters **b[3]**, **b[4]**, **b[5]**, **b[12]**, **b[15]**, **b[17]**, and **b[18]**, respectively, in functions at that level. The information required by Level 1 from Level 2 is the total primary production for each day; that part of the total assigned to diatoms, cyanobacteria, and chlorophytes; and the total export of dissolved organic matter from periphyton. At the conclusion of the 16 iterations in Level 2, values for these variables are stored in the five state variables **x[1]**, **x[2]**, **x[3]**, **x[4]**, and **x[5]** which are represented by the Level 2 output variables **y[1]**, **y[2]**, **y[3]**, **y[4]**, and **y[5]**. The output variables from Level 2 are passed up to Level 1 and become **g[30]**,

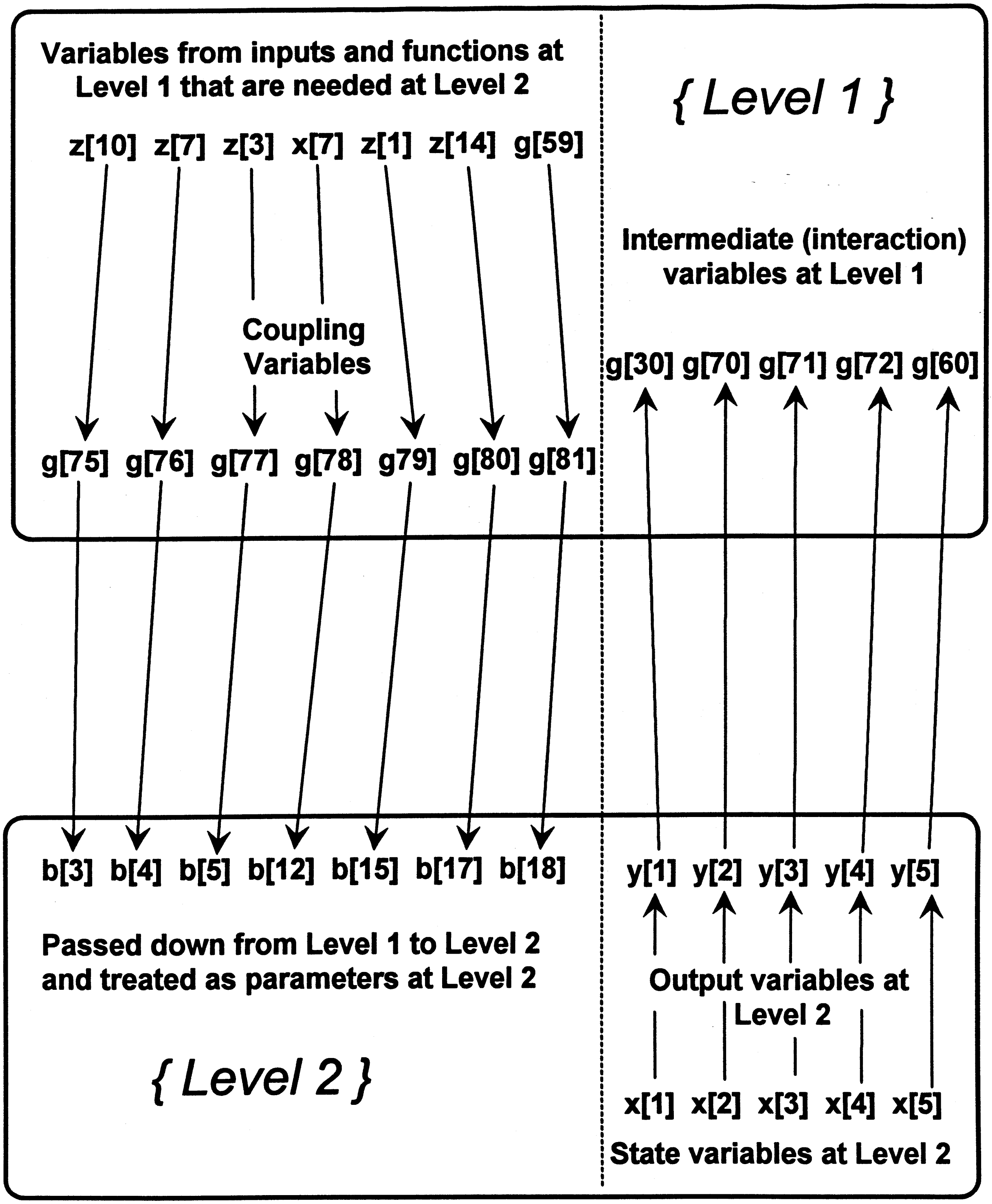


Figure 21. Systems diagram depicting the coupling structure of the Riparian Version of the M & C Stream Model.

g[70], **g[71]**, **g[72]**, and **g[60]**, respectively, in Level 1. It is important to emphasize at this point that each level of resolution has a unique numbering system for variables, i. e., a variable with a particular number usually will not represent the same thing at both levels. For example, the variable **g[7]** represents daily emergence losses associated with shredders in Level 1 and the hourly increment of primary production in Level 2.

To further illustrate the 2-level approach to modeling, the four major equations for the calculation of the hourly primary production increment at Level 2 are given below with some comments about notation. For a complete mathematical documentation of the Riparian Version of the M & C Stream Model, the user may refer to Appendix IX.

The equation for the nutrient limiting effect on primary production at Level 2 is

$$g_1 = \left\{ \begin{array}{ll} \dfrac{b_8 b_5}{1 + b_8 b_5} & \mathit{if}\ b_5 < b_6 \\ 1 - \left(\dfrac{1}{1 + b_6 b_8}\right)\left(\dfrac{b_7 - b_5}{b_7 - b_6}\right) & \mathit{if}\ b_6 \le b_5 < b_7 \\ 1 & \mathit{if}\ b_7 \le b_5 \end{array} \right\}$$

This equation is exactly the same as the equation for **g[14]** in Version I and the Herbivory Version of the model (Appendix I, page 157). In the Riparian Version, the nutrient limiting effect is calculated in Level 2; and the nutrient concentration, which is the input variable **z[3]** introduced in Level 1, is past down through the coupling variable **g[77]** and becomes the parameter **b[5]** in Level 2 (Fig. 21). The reason that the table of nutrient concentrations is introduced into Level 1, instead of directly into Level 2, is that the values in the table (XNUTR) represent daily average conentrations. In other words, the nutrient data is not detailed enough to present it at an hourly resolution, and therefore, it is appropriate to treat the concentration as a constant (i. e., as a *b* parameter) during the 16 iterations that represent one day in Level 2. The other parameters **b[6]**, **b[7]**, and **b[8]** in the Level 2 equation are assigned the same values (for the Standard Run) as **b[68]**, **b[69]**, and **b[78]** in the function for **g[14]** in Version I and the Herbivory Version (Appendix I, page 157).

The equation for the light limiting effect on primary production is

$$g_2 = \begin{cases} \dfrac{b_{10}z_2}{1 + b_{10}z_2} & \textit{if } z_2 < b_9 \\ 1 - \left(\dfrac{1}{1 + b_9 b_{10}}\right)\left(\dfrac{b_{11} - z_2}{b_{11} - b_9}\right) & \textit{if } b_9 \le z_2 < b_{11} \\ 1 & \textit{if } b_{11} \le z_2 \end{cases}$$

In this case, **z[2]** is the light intensity at the bottom of the stream, a value that is a function of the **z[1]**. The input variable **z[1]** is derived from the table of light energy inputs (LITETAB.RUN) that is set up on an hourly resolution and introduced directly into Level 2. The general rule is to introduce input variables into the level that corresponds to the time resolution of the data in the input table. The mathematical structure of the equation for the light limiting effect **g[2]** is exactly the same as the equation for **g[15]** in Version I and the Herbivory Version of the model (Appendix I, page 157). For the Standard Run of the Riparian Version, the parameters **b[9]**, **b[10]**, and **b[11]** are assigned the same values as the parameters **b[90]**, **b[71]**, and **b[91]**, respectively, in the equation for **g[15]**.

The biomass and temperature limiting effects on primary production are represented by the variable **g[3]** in Level 2 of the Riparian Version of the model; the corresponding equation has the same mathematical form as the equation for **g[31]** in Version I and the Herbivory Version (Appendix I, page 162). The equation in Level 2 is

$$g_3 = \left(\frac{b_{13}b_{12}}{1 + b_{13}b_{12}}\right)\left(\frac{b_{14}b_{15}}{1 + b_{14}b_{15}}\right) .$$

In this function, the parameter **b[12]** represents the the periphyton biomass which is passed down from Level 1 through the coupling variable **g[78]** (Fig. 21). In Level 1, the periphyton biomass is the state variable **x[7]** and is updated at a daily resolution by the variable **f[7]** (see pages 147- 148 in Appendix I for details). Because the losses associated with the periphyton biomass (e.g., respiration, export, and grazing) are calculated at a temporal resolution of one day, it is necessary to treat the biomass as a constant (i. e., a *b* parameter) in Level 2. Therefore, the only component of the periphyton biomass that runs at an hourly resolution is the photosynthetic component; the other components that represent the energy losses run at a daily resolution in Level 1. The temperature data are also introduced at a daily resolution into Level 1 and are treated as a parameter (**b[15]**) in Level 2. The other parameters in the equation (**b[13]** and **b[14]**) correspond to the parameters **b[76]** and **b[77]**, respectively, in the equation for **g[31]** in Version I and the Herbivory Version (Appendix I, page 162).

After calculating the factors that limit primary production in Level 2 at an hourly resolution, the hourly increment of photosynthesis, which is represented by the variable **g[7]**, can be calculated. The equation for **g[7]** is

$$g_7 = 0.937\, b_{16} g_1 g_2 g_3 b_{17} ,$$

where b_{16} is the maximum possible photosynthetic rate, g_1 is the nutrient limiting factor, g_2 is the light limiting factor, g_3 is the biomass and temperature limiting factor, and b_{17} is the current velocity limiting factor, a variable **z[14]** in Level 1 that is passed down and treated as a parameter in Level 2. The equation for the variable **g[7]** in the Riparian Version of the model is the same, with different notation, as the equation for **g[30]** in Version I and the Herbivory Version (Appendix I, page 162).

Structure of the Command File

The structure of the command file for the Riparian Version of the M & C Stream Model (RIPARIAN.CMD) is similar to the command file for Version I (see page 17), with the important exception that the Riparian Version requires two sets of commands (instead of one set), each corresponding to a different level of temporal resolution. The command file used for the Standard Run of the Riparian Version is:

line 1: **LEVEL=1**
line 2: **IB(1:10)=0,1.39E-2,5.7E-2,-1,0,0.114,0.581,1.97E-4,-94.4,9.42E3**
line 3: **IB(11:20)=1.08E3,4.88E-2,8.83E-2,10.2,2.295E-3,1.07,0.633,1.1,1.6E2,1.5**
line 4: **IB(21:30)=4,0.8,1,4,0.5,0,0,3.5,3.5,0**
line 5: **IB(31:40)=9.95E-2,0.465,0.895,0.56,1.9,1.51,0.294,2.03,1.28E-4,1.28E-4**
line 6: **IB(41:50)=1.38E-3,1.38E-3,-1,0,0.187,2.33E-3,1.74E-2,0,0,0.3**
line 7: **IB(51:60)=0.86,0.1,1.87E-3,2.5E-3,2.6E-2,1.88E-2,0.42,0.82,0.05,100**
line 8: **IB(61:70)=0,0,0,3,0.01,2.8E-2,0.583,1.0E-3,0.5,1.92E-2**
line 9: **IB(71:80)=2.1E-3,0.7,0,7.4E-3,1.08E-3,0.1,0.4,2.68E2,2.95,0.187**
line 10: **IB(81:90)=1.46E-2,2.96E-2,1.46E-2,15,0.8,12,0.35,0.7,0.237,1.0E3**
line 11: **IB(91:100)=2.4E3,0.55,0.18,0.21,0,0.3,0.3,0.3,0.167,1**
line 12: **IB(101:107)=4.46E-3,4.46E-3,4.46E-3,-1,1.44E-4,0,5.85E-2**
line 13: **IB(108:114)=9.11E-4,1.99E-4,5.85E-2,-1,-1,-1,-1**
line 14: **IB(115:123)=3.0E-2,1.75E-2,2.5E-2,-2.83E-2,0.849,1,0.28,1,1**
line 15: **IX(1:11)=0,1.056,1.258,2.357,3.708,.11,1.244,7.626,127.2,25.252,30.851**
line 16: **IX(12:17)=1.145,16.978,0.668,1.266,0,0**
line 17: **IM(2:7)=0.0,0.0,0.0,0.0,0.0,0.0**
line 18: **TARGET**
line 19: **SSET=(2:17)**
line 20: **SINT=30**
line 21: **TSTOP=360**

line 22: **PFILE=RIP.OUT**
line 23: **PSET=X(2:7,15:17)**
line 24: **PINT=10**
line 25: **TABLE(2)=XNUTR**
line 26: **TABLE(3)=STRFLOW**
line 27: **TABLE(4)=SALLOC**
line 28: **TABLE(5)=FALLOC**
line 29: **TABLE(6)=GEMER**
line 30: **TABLE(7)=SEMER**
line 31: **TABLE(8)=CEMER**
line 32: **TABLE(9)=PEMER**
line 33: **TABLE(10)=STRTEMP**
line 34: **LEVEL=2**
line 35: **AUTORESET**
line 36: **IB(1:2)=1,1**
line 37: **IB(6:11)=1.0E-3,0.5,2.68E2,1.0E3,2.1E-E,2.4E3**
line 38: **IB(13,14,16,19,20)=0.1,0.4,2.95,.028,.583**
line 39: **IX(1:5)=0,0,0,0,0**
line 40: **TSTOP=16**
line 41: **TABLE(1)=LITETAB.RUN**

The command file for a two-level model consists of two parts, one that begins with the **LEVEL=1** command and the other with the **LEVEL=2** command. In the example for the Riparian Version, there are 33 commands associated with Level 1 and 8 commands that are related to Level 2. The **LEVEL=?** command indicates that all of the commands below that line apply to the designated level, until a new **LEVEL=?** command is encountered. For the Standard Run of the Riparian Version, the file introduces 123 parameters that are used in functions that run at a daily time resolution in Level 1. Initial values for state variables and memory variables also are specified for Level 1, variables that represent the same biological components introduced for the Herbivory Version of the model. The **TARGET** command on line 18 of the file specifies the desired level for the screen, print file, and dump file output, Level 1 in this case. If the user wants to monitor Level 2 on the screen, the **TARGET** command is moved to any position below the **LEVEL=2** command. Alternatively, the user can change the target level before a simulation run while in the FLEX model processor (see example in the next section). Lines 19-24 simply specify the Level 1 output variables and time increments for the screen and print file. The corresponding displays on the screen and print file will only occur if the **TARGET** command is located between the **LEVEL=1** and **LEVEL=2** commands. Lines 25-33 specify the input tables for Level 1. In this case, these tables are set up for a Standard Run and are the same as the tables introduced for a Standard Run of Version I and the Herbivory Version of the model. However, notice that the table of illumination values (EXLITE) is not introduced into Level 1. In the Riparian Version of the model, the light energy schedule operates on an hourly resolution, and therefore, it is introduced below the **LEVEL=2** command as the table LITETAB.RUN, a 360 X 16 matrix of irradiation values expressed as μmol quanta m^{-2} s^{-1}. Level 2 requires 20 parameters (**b[1]** - **b[20]**), 12 of which must be specified in the command file below the **LEVEL=2** command, or while in the FLEX processor before the simulation run. The parameters **b[3]**, **b[4]**, **b[5]**, **b[12]**, **b[15]**, **b[17]**, and **b[18]** are passed down from variables in Level 1 (Fig. 21), and therefore, are not specified in the command file or while in the model processor.

Four state variables (**x[1]**, **x[2]**, **x[3]**, and **x[4]**) in Level 2 represent the incremental accumulation of photosynthate during a 16-hour period. At the beginning of each day, net accumulation is zero, and by the end of the day, the total accumulation (**x[1]**) and the fractional accumulations in diatoms (**x[2]**), cyanobacteria (**x[3]**), and chlorophytes (**x[4]**) are passed up to Level 1 (Fig. 21). The state variable **x[5]** is the export of dissolved organic matter from periphyton and its value at the end of a day is passed up to Level 1 (Fig. 21).

The initial values for all five state variables in Level 2 are equal to zero (see line 39 in the command file). The **AUTORESET** command (line 35) resets these values back to zero at the beginning of each day, and the **TSTOP=16** command sets the number of iterations in Level 2 to 16, corresponding to a maximum daylength of 16 hours. Seasonal changes in daylength are controlled by the values in LITETAB.RUN, the table of irradiation values. For example, in the winter when the period of daylight is only 8 hours, the first and last four entries on a line of inputs are equal to zero. Therefore, photosynthate acccumulates only during hours 5 - 12, a period corresponding to an 8-hour period of daylight. Because photoperiod is controlled by the values in LITETAB.RUN, it is not necessary to introduce the table PHOTPER, the table of daylengths required by Version I and the Herbivory Version of the model (see line 32 in the command file on page 17).

Simulation Procedures

Simulation procedures for the Riparian Version of the model are very similar to procedures described for Version I and the Herbivory Version (see pages 10-16 and pages 44-52). To produce a Standard Run of the Riparian Version, it is first necessary to set up a new subdirectory with the necessary program and supporting files. Log on the root directory of the C drive of your computer, insert the enclosed diskette into the A drive slot, and type

C:\>**cd model** (return)

C:\MODEL>**md ripar** (return)

C:\MODEL>**cd ripar** (return)

C:\MODEL\RIPAR>**copy a:\ripar*.*** (return)

C:\MODEL\RIPAR>**dir** (return)

These commands set up a new subdirectory named RIPAR and transfer all files required to run the Riparian Version of the model. Files listed by the **dir** command include the compiled program file (RIPARIAN.COM), a corresponding Pascal code file (RIPARIAN.PAS), the command file (RIPARIAN.CMD), the input files listed in the command file, files needed to generate the energy budget (RIPARTAB.COM, RIPARTAB.CMD, and BUDGET.COM), and some supporting files that can be used to generate new tables of light energy inputs. To produce a Standard Run, type

C:\MODEL\RIPAR>**riparian** (return)

CMD>**read=riparian.cmd** (return)

CMD>**run** (return)

Because the **TARGET** command in the command file is located between the **LEVEL=1** and **LEVEL=2** commands, the screen and print file (RIP.OUT) output will display the variables requested by the **sset** and **pset** commands for Level 1. To observe state variable dynamics in Level 2 on the screen at a 4-hour time resolution, press the return key and type

CMD>**reset** (return)

CMD>**level=2** (return)

CMD>**target** (return)

CMD>**sset=x(1:4)** (return)

CMD>**sint=4** (return)

CMD>**run** (return)

To return to Level 1 and rerun the model, type

CMD>**reset** (return)

CMD>**level=1** (return)

CMD>**target** (return)

CMD>**run** (return)

CMD>**q** (return)

The procedure for changing parameters in the Riparian Version of the model is the same as that described for the other versions with the exception that the user must make sure that the correct model level is specified before the new values are entered. For example, type

C:\MODEL\RIPAR>**riparian** (return)

CMD>**read=riparian.cmd** (return)

CMD>**level=1** (return)

CMD>**ib(72)=3.0** (return)

CMD>**tstop=7200** (return)

CMD>**sint=360** (return)

CMD>**run** (return)

(Write down state variable values for day 7200) (return)

CMD>**reset** (return)

CMD>**tstop=360** (return)

CMD>**sint=15** (return)

CMD>**sset=x(2:7,15:17)** (return)

CMD>**ix(2:9)=2.213,.791,.813,5.232,.561,4.527,6.461,160.444** (return)

CMD>**ix(10:14)=30.893,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=4.346,.27,2.085E-2** (return)

CMD>**run** (return)

CMD>**q** (return)

This set of commands changes the algal refuge parameter **b[72]** from its standard value of 0.7 g m^{-2} to a new value of 3.0 g m^{-2}. The first part of the run determines the steady state initial values for the 17 state variables in Level 1, and the second part simulates the steady state behavior with the new parameter value and displays the results on the screen for a 360-day (1 year) period at a 15-day resolution. In this case, it is necessary to insert the **level=1** command before introducing the new value for **b[72]**, because in the command file, the **LEVEL=2** command is located below the **LEVEL=1** command, which means that any changes in parameters or initial conditions will relate to Level 2 until a new command is encountered that changes the level. To avoid confusion, it is good practice to always insert the **level=?** command before changing parameters or initial conditions, even if the proper level is designated in the command file.

For a second example of changing a parameter value, the parameter **b[2]** is changed in Level 2. In Level 2, **b[2]** is a light energy multiplier that allows the user to rescale the irradiation input variable **z[1]**. After each value is read from the input table LITETAB.RUN, it is multiplied by the constant **b[2]**. For the Standard Run, **b[2]** = 1, so the inputs remain the same as the values in the table. For the example, assume that the user wants to study model behavior for the case in which irradiation inputs are three times the standard values in LITETAB.RUN. The necessary commands for this run are

C:\MODEL\RIPAR>**riparian** (return)

CMD>**read=riparian.cmd** (return)

CMD>**level=2** (return)

Note: In this case, the above command in not really necessary, because the **LEVEL=2** *command is below the* **LEVEL=1** *command in the command file* RIPARIAN.CMD. *However, it is recommended that the user alway includes the* **level=?** *command before changing parameters or initial conditions to avoid mistakes when the same parameter number occurs in both levels.*

CMD>**ib(2)=3** (return)

CMD>**level=1** (return)

CMD>**tstop=7200** (return)

CMD>**sint=360** (return)

Note: It is necessary to change the command level back to Level 1, because the run length must be extended to 7200 days in order to obtain steady state initial values for state variables. If the **level=1** *command is not inserted, the model will run for 7200 hours instead of 7200 days!*

CMD>**run** (return)

(Write down state variable values for day 7200) (return)

CMD>**reset** (return)

CMD>**tstop=360** (return)

CMD>**sset=x(2:7,15:17)** (return)

CMD>**sint=30** (return)

CMD>**ix(2:9)=2.252,1.134,1.226,3.21,.301,1.056,8.471,137.298** (return)

CMD>**ix(10:14)=26.983,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=1.075,0,0** (return)

CMD>**run** (return)

CMD>**q** (return)

This set of commands will generate the usual screen and print file (RIP.OUT) output for Level 1 after a parameter change is made in Level 2.

As a final example of changing parameters in the Riparian Version of the model, irradiation inputs are doubled in Level 2, the minimum value for the food quality limiting factor (**b[121]**) is increased from 0.28 to 0.7 in Level 1, and the algal refuge parameter (**b[72]**) is increased from 0.7 to 4 g m^{-2} in Level 1. The necessary commands for this simulation run are

C:\MODEL\RIPAR>**riparian**	(return)
CMD>**read=riparian.cmd**	(return)
CMD>**level=2**	(return)
CMD>**ib(2)=2**	(return)
CMD>**level=1**	(return)
CMD>**ib(72)=4**	(return)
CMD>**ib(121)=0.7**	(return)
CMD>**tstop=7200**	(return)
CMD>**sint=360**	(return)
CMD>**run**	(return)
(Write down state variable values for day 7200)	(return)
CMD>**reset**	(return)
CMD>**tstop=360**	(return)
CMD>**sset=x(2:7,15:17)**	(return)
CMD>**sint=30**	(return)

CMD > **dfile=ripb247.txt** (return)

CMD > **dint=1** (return)

CMD > **dset=x(2:7,15:17)** (return)

CMD > **ix(2:9)=3.61,.563,.573,17.063,.624,6.597,6.695,177.622** (return)

CMD > **ix(10:14)=33.606,30.851,1.145,16.978,.668** (return)

CMD > **ix(15:17)=6.261,.429,.154** (return)

CMD > **run** (return)

CMD > **q** (return)

This set of commands also includes a request for a dump file (RIPB247.TXT) which contains biomass values for the major processes and algal functional groups at a time resolution of one day. These values were imported into a plotting program (SIGMAPLOT) to produce the graphs in Figure 22. For comparison, the corresponding graphs for the the Standard Run are illustrated in Figure 23. In the Standard Run, the model predicts that the periphyton biomass consists of diatoms, and the biomass of the other functional groups of algae is negligible throughout year (Fig. 23). However, with the change in parameters, both cyanobacteria and chlorophytes appear in the periphyton assemblage, and the capacity of the system to support grazers and predators increases significantly (Fig. 22).

The user also has the option of producing an energy budget for each run of the Riparian Version of the model. For this purpose, the program RIPARTAB.COM and its command file RIPARTAB.CMD will give the same simulation run as RIPARIAN.COM while calculating the additional variables that are needed to create the three tables for the energy budget. Therefore, RIPARTAB.COM serves the same purpose as STRMTAB.COM and

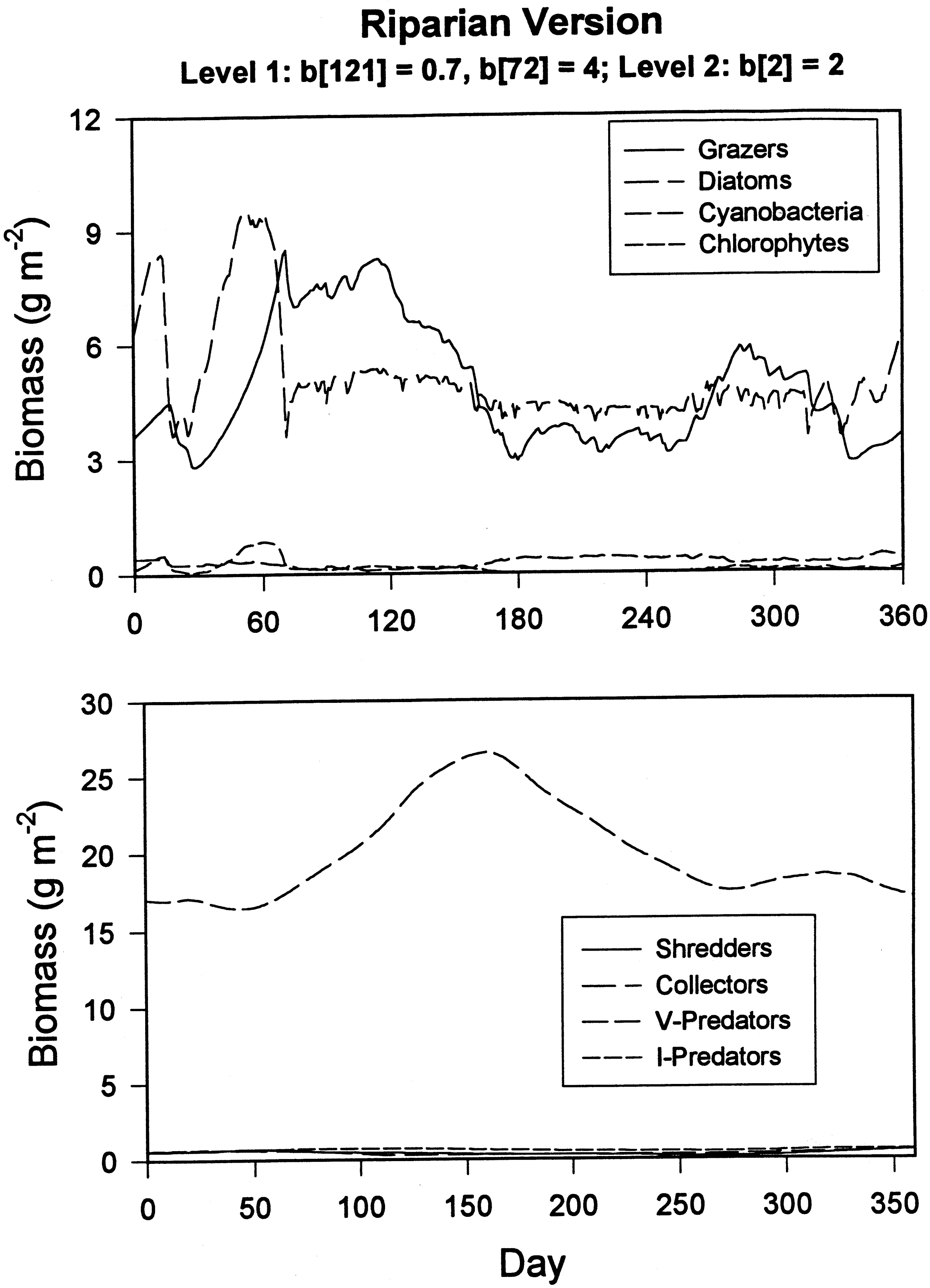


Figure 22. Seasonal dynamics of state variables representing the major biological processes in the Riparian Version of the M & C Stream Model. The run conditions are Level 1: $b_{121} = 0.7$, $b_{72} = 4$; Level 2: $b_2 = 2$.

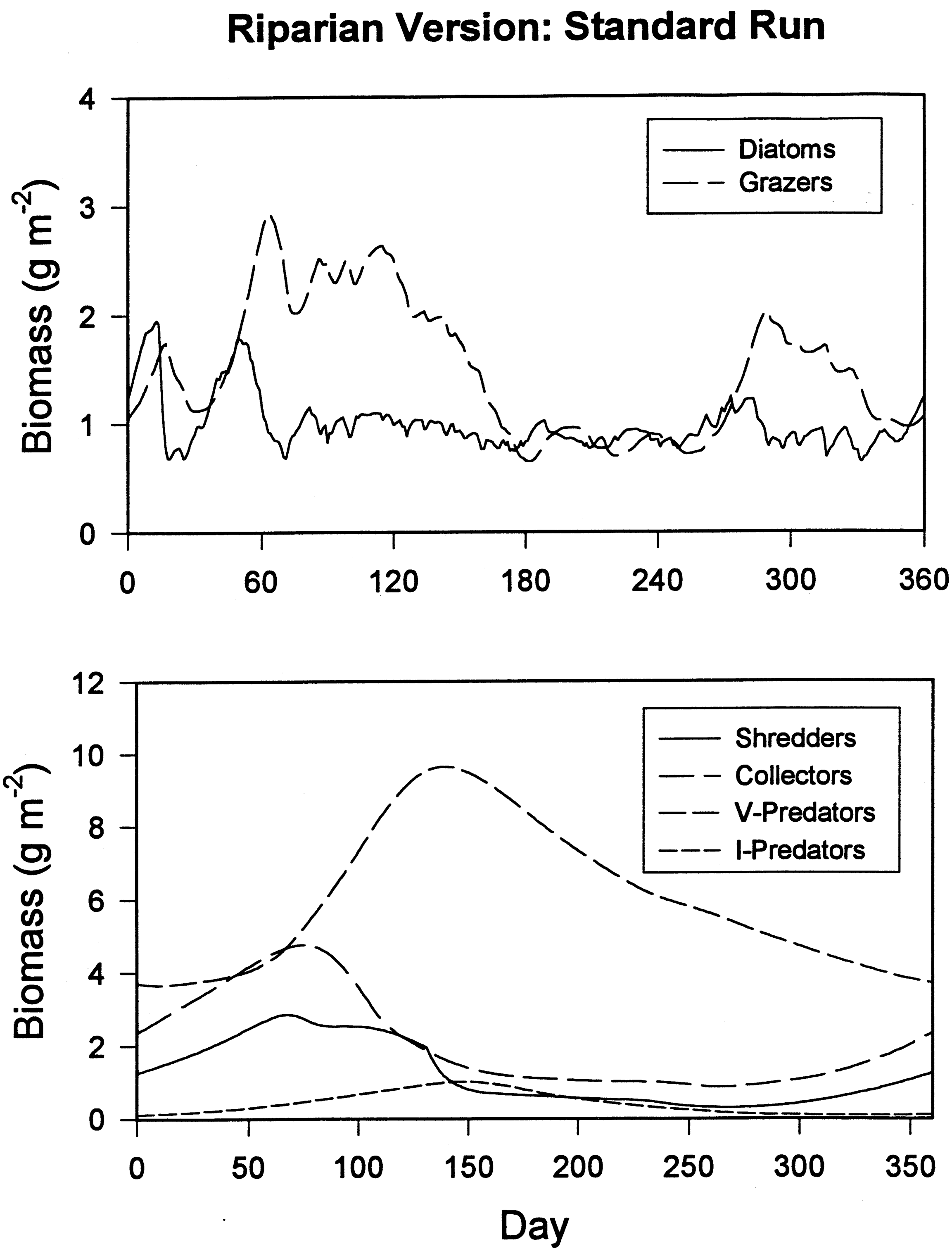


Figure 23. Seasonal dynamics of state variables representing the major biological processes in the Riparian Version of the M & C Stream Model. Curves represent output from the Standard Run.

HERBTAB.COM discussed in earlier sections of this manual. Because of the voluminous output generated by RIPARTAB.COM, which is stored in the output file STREAM.DMP, and a corresponding relatively slow run time, it is recommended that RIPARIAN.COM be used instead of RIPARTAB.COM for all simulation runs that do not require the calulation of the annual energy budget. To generate an energy budget for the last example, type

C:\MODEL\RIPAR>**ripartab**	(return)
CMD>**read=ripartab.cmd**	(return)
CMD>**level=2**	(return)
CMD>**ib(2)=2**	(return)
CMD>**level=1**	(return)
CMD>**ib(72)=4**	(return)
CMD>**ib(121)=0.7**	(return)
CMD>**ix(2:9)=3.61,.563,.573,17.063,.624,6.597,6.695,177.622**	(return)
CMD>**ix(10:14)=33.606,30.851,1.145,16.978,.668**	(return)
CMD>**ix(15:17)=6.261,.429,.154**	(return)
CMD>**run**	(return)
CMD>**q**	(return)
C:\MODEL\RIPAR>**budget**	(return)
(Enter run title)	(return)

The output from the program BUDGET.COM is stored in the file STREAM.TAB as described for the other versions of the model. Moreover, the programs BUD2YR.COM, BUD3YR.COM, and BUD4YR.COM also can be used instead of BUDGET.COM when the system exhibits cycles greater than one year.

Most of the parameter numbers in Level 1 of the Riparian Version of the model are the same as the numbers in the Herbivory Version. This convention was followed to avoid confusion and the necessity of learning a new set of numbers for the Riparian Version. The original numbers for the parameters in the Herbivory Version that were moved to Level 2 in the Riparian Version are retained and assigned zero values in Level 1, and do not appear in any functions in Level 1. If the model is reprogrammed from the documentation in Appendix IX, the unused parameters in Level 1 can be eliminated and the other parameters renumbered in a consecutive array. A list of a few parameters that can be used in simulation runs to help the user become more familiar with the properties of the Riparian Version of the model is given below. For a complete list, the user can refer to the mathematical documentation in Appendix IX.

Parameter	Standard Value	Level	Explanation
b_{92}	0.55	1	grazer assimilation ratio
b_{93}	0.18	1	shredder assimilation ratio
b_{94}	0.21	1	collector assimilation ratio
b_{58}	0.82	1	invertebrate predator assimilation ratio
b_{51}	0.86	1	vertebrate predator assimilation ratio
b_{72}	0.7	1	algal refuge parameter ($g\ m^{-2}$)
b_{96}	0.3	1	grazer refuge parameter ($g\ m^{-2}$)
b_{97}	0.3	1	shredder refuge parameter ($g\ m^{-2}$)
b_{98}	0.3	1	collector refuge parameter ($g\ m^{-2}$)
b_4	-1	1	constant temperature
b_{100}	1.0	1	grazer food demand multiplier

b_{111}	-1	1	constant NO_3 (nutrient) concentration
b_{114}	-1	1	constant allochthonous input (slow)
b_{104}	-1	1	constant allochthonous input (fast)
b_{121}	0.28	1	food quality limiting factor minimum
b_1	-1	2	constant irradiance
b_2	1.0	2	irradiation table multiplier
b_{16}	2.95	2	maximum possible rate of primary production expressed as O_2 m^{-2} hr^{-1}

Manipulation of Irradiation Inputs

The irradiation data required to run the Riparian Version of the model is considerably more detailed than the daily mean estimates of illumination that are tabulated in EXLITE, the table of inputs used for the Standard Run of both Version I and the Herbivory Version of the model. If local irradiation data is not available in the form required by the Riparian Version, it is still possible to construct hypothetical tables of inputs that may be relevant to objective questions of interest to the user. To aid the user in the construction of such tables, the enclosed diskette contains the following supporting files in the RIPAR and BACKUP subdirectories: LITETAB.PAR, LITECHG.COM, GENVEC.COM, and MAXMEAN.COM.

The file LITETAB.PAR is a table of irradiation values measured in an open, unshaded area of the H. J. Andrews Experimental Forest in western Oregon. The values in the table represent hourly mean values that have been corrected to estimates of photosynthetically active radiation (PAR). If this table is introduced as irradiation inputs into Level 2 of the Riparian Version, the simulation run that follows corresponds to a stream that receives direct radiation from the sun, without shading at any time of the year. The user can examine the maximum and mean values of this table or any other input table that is structured as 360 x 16 matrix by typing

C:\MODEL\RIPAR>**ren** <*table name*> **litetab.run** (return)

C:\MODEL\RIPAR>**maxmean** (return)

C:\MODEL\RIPAR>**ren litetab.run** <*table name*> (return)

The program MAXMEAN.COM will read in any file with the name LITETAB.RUN, determine the maximum value for each line (day), and then sum the 16 values in each line and divide by 16 to generate a daily mean value. The outputs from this program are two files, TABMAX and TABMEAN, which consist of linear arrays of 360 maximum and mean values, respectively. The files TABMAX and TABMEAN can be use to plot the patterns for each table of inputs. Plots of daily maximum and mean values for LITETAB.PAR are presented in Figure 24.

In most cases, the user will want to provide irradiation inputs that simulate various seasonal patterns of shading in relation to the structure of the riparian zone canopy of terrestrial vegetation. The program LITECHG.COM allows the user to contour the data in LITETAB.PAR to a desired pattern of shading. To accomplish this, the user must create a one-dimensional table (360 rows and 1 column) that contains the proportions of total irradiation that are allowed to reach the water surface of the stream. The corresponding file is named LITEVEC. After this file is created, and with LITETAB.PAR stored on the same subdirectory, type

C:\MODEL\RIPAR>**ren litetab.par litetab** (return)

C:\MODEL\RIPAR>**litechg** (return)

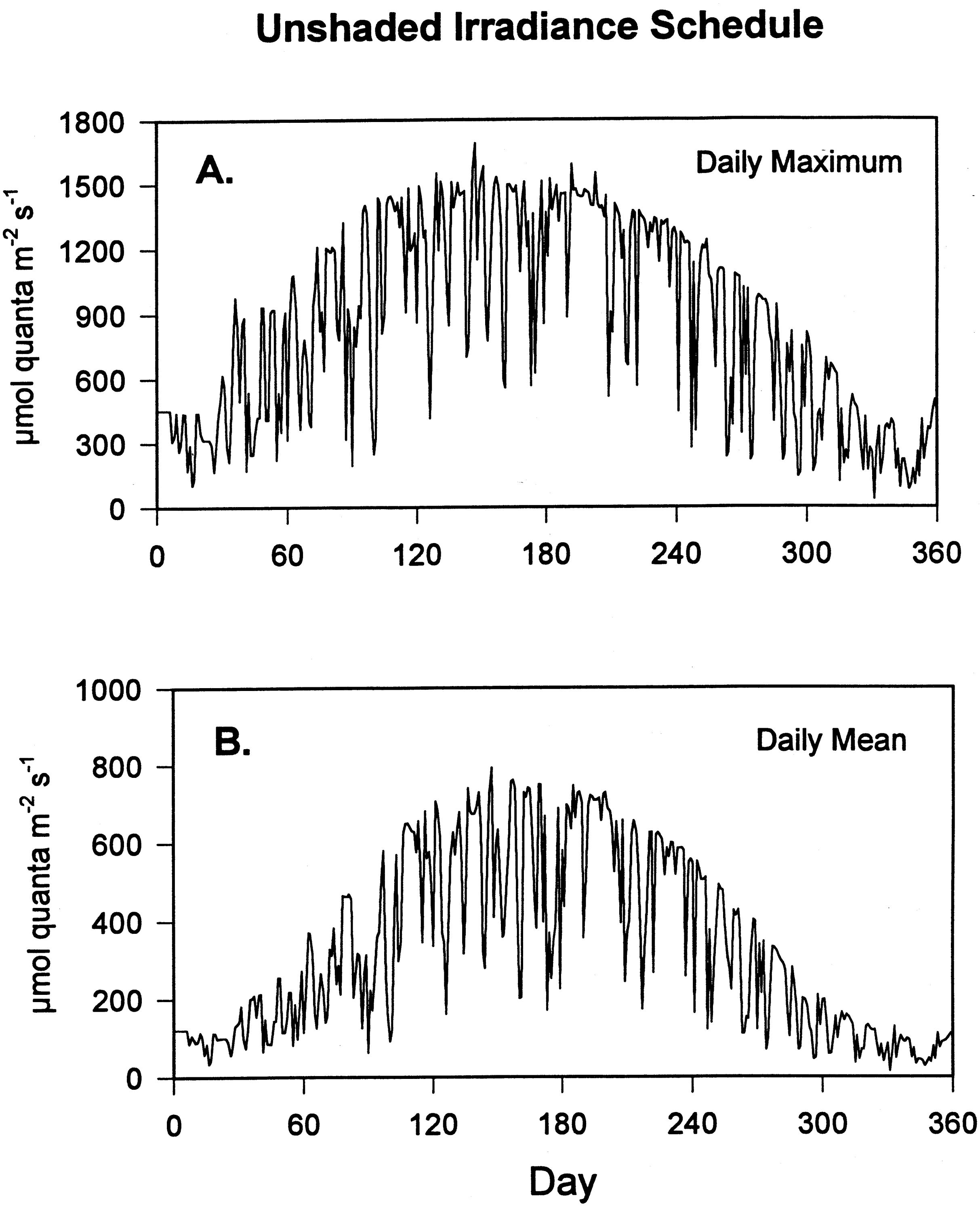


Figure 24. Daily maximum (A) and mean (B) irradiance for an open forest canopy. Data are based on measurements from the Andrews Experimental Forest.

C:\MODEL\RIPAR> **ren litetab litetab.par** (return)

With these commands, the program LITECHG.COM will read the matrix of total irradiation values from LITETAB, multiply the 16 values in each row by the corresponding proportion in LITEVEC, and output a new table of irradiation values with the name LITETAB.RUN. Before LITECHG.COM is executed, it is necessary to rename the file that the user wishes to modify, because LITECHG expects an input table named LITETAB. In the case of the Standard Run for the Riparian Version of the model, the vector of proportions is stored in the file LITEVEC.STD. Therefore, the commands that generate the light energy inputs for the standard run and produce the file necessary to plot the maximum and mean values are

C:\MODEL\RIPAR> **ren litevec.std litevec** (return)

C:\MODEL\RIPAR> **ren litetab.par litetab** (return)

C:\MODEL\RIPAR> **litechg** (return)

C:\MODEL\RIPAR> **ren litevec litevec.std** (return)

C:\MODEL\RIPAR> **ren litetab litetab.par** (return)

Note: At this point, the program LITECHG.COM *has created a new table of irradiation values with the file name* LITETAB.RUN, *the file name that is required by the program* MAXMEAN.COM.

C:\MODEL\RIPAR> **maxmean** (return)

The plot of the maximum and mean values for the irradiation inputs set up for the Standard Run are presented in Figure 25. These graphs illustrate how the table of total irradiation values (LITETAB.PAR) have been contoured to reduce inputs during late spring and summer when shading by riparian zone vegetation is assumed to occur.

If the user wants to multiply each value in a table of irradiation inputs by a constant, there are two alternative ways to accomplish this transformation. The approach described on page 108 is to change the parameter **b[2]** from unity to the desired constant. This is the best approach when the number of simulation runs that require the modified table is small. However, if a long series of runs is anticipated, a better approach is to generate a new table with the desired change and simply designate this table in the command file. By changing the command file in this manner, the user will not have to change the parameter **b[2]** before each simulation run, because the input table itself has been changed before it is read in by the model processor. To help the user make changes in the input table, a program entitled GENVEC.COM is available on the MODEL\RIPAR subdirectory. For example, assume that the user wishes to introduce an irradiance schedule that is exactly one-half of the values in LITETAB.PAR. To construct the required table, type

C:\MODEL\RIPAR>**genvec** (return)

At this point the user is prompted for the constant by "Please enter the value for the vector". Now, type

0.5 (return)

C:\MODEL\RIPAR>**ren litetab.par litetab** (return)

C:\MODEL\RIPAR>**litechg** (return)

C:\MODEL\RIPAR>**ren litetab litetab.par** (return)

After the desired constant is entered, the program GENVEC.COM generates the file LITEVEC that contains a single array of 360 numbers, each equal to the constant entered after the prompt. The next command changes the name of the table that the user wishes to modify to LITETAB, the name required by the program LITECHG.COM. After executing

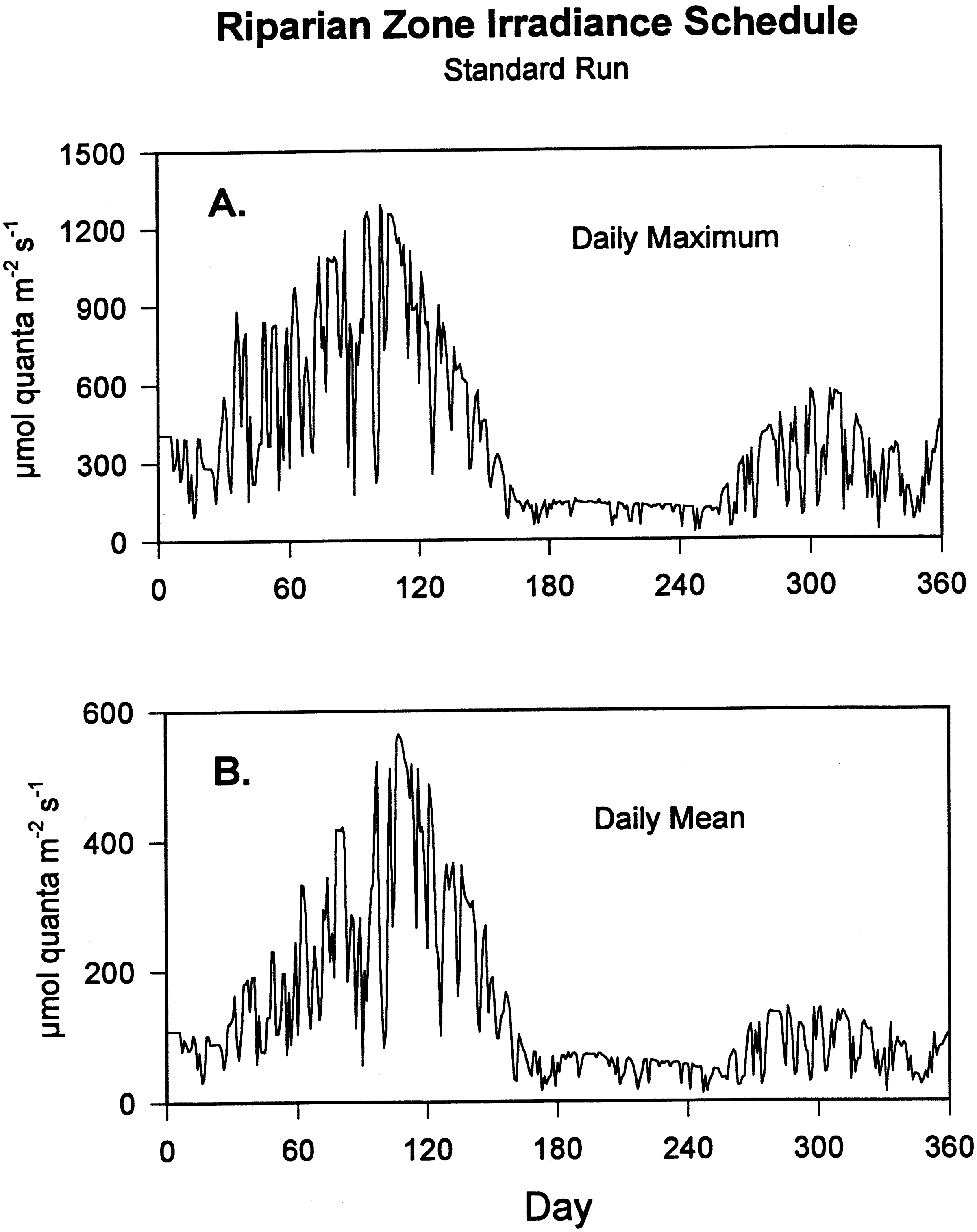


Figure 25. Daily maximum (A) and mean (B) irradiance for a shaded forest canopy. This irradiance schedule is used for the Standard Run of the Riparian Version of the M & C Stream Model.

LITECHG.COM, the modified table LITETAB.RUN is stored on the subdirectory MODEL\RIPAR. The last command simply changes the name of the file LITETAB to its original name LITETAB.PAR.

A summary of the input and output files associated with the three programs that manipulate irradiation schedules for the Riparian Version of the model is tablulated below:

Program	Input File	Output File
MAXMEAN	LITETAB.RUN	TABMAX, TABMEAN
LITECHG	LITEVEC, LITETAB	LITETAB.RUN
GENVEC	none	LITEVEC

As a word of caution, it is recommended that the user develop a system for naming the files that are being used for irradiation inputs. For example, the program LITECHG will always generate an output table with the name LITETAB.RUN. If there is another table with the same name stored on the subdirectory, the execution of LITECHG.COM will destroy the old table and replace it with a new table with that name. Consequently, if the user wants to keep the original table, it must be renamed before LITECHG.COM is executed again. Likewise, the files that create the standard table of inputs (LITEVEC.STD and LITETAB.PAR) must be renamed LITEVEC and LITETAB before they can be used as input into LITECHG.COM. If the original names of these files are not restored, LITEVEC.STD, now with the name LITEVEC, will be lost if the user executes the program GENVEC.COM. As a precaution, the files related to the irradiation inputs for the Riparian Version of the model are stored on the enclosed diskette in the subdirectory RIPAR and in a backup subdirectory named BACKUP. This subdirectory organization will allow the user to restore files to the RIPAR subdirectory if they are accidentally deleted during execution of LITECHG.COM or GENVEC.COM. Also, the TURBO PASCAL code files for LITECHG.COM, GENVEC.COM, and MAXMEAN.COM (LITECHG.PAS, GENVEC.PAS, and MAXMEAN.PAS) are included on the BACKUP subdirectory in case the user wants to change the input/output names or modify the programs for other purposes.

Manipulations of Input Tables and Parameters: An Example

In this section, effects of three parameters on the behavior of the Riparian Version of the model are examined in relation to two irradiation schedules. The proposed problem requires 32 simulation runs, each with a unique combination of parameter values and schedule of irradiation and allochthonous inputs. The user can work through the entire sequence of 32 runs or some subset of the runs, depending on the relevance of the Riparian Version to individual needs. Results of the simulations are presented as a series of graphs that depict annual production rates for the six major biological processes represented by the model (i.e., grazing, shredding, collecting, vertebrate predation, invertebrate predation, and primary production). Annual production rates are only one of the many classes of output variables that can be investigated by a series of model simulations. Examples of other such variables include respiratory expenditures, export rates, emergence losses, assimilation rates, food consumption rates, and biomass turnover times. If the user has the time to generate annual energy budgets for the 32 simulations runs, it is recommended that the manipulations of input tables and parameter values also be investigated in relation to some of these other variables.

The proposed series of simulation runs for the Riparian Version of the model is summarized in Table 5. One-half of the runs (16) are designed to simulate a stream that is shaded during the summer and early fall, whereas the other half of the runs simulate a stream exposed to full sunlight (unshaded) during the entire year. The irradiation schedules used to simulate shaded and unshaded (open) conditions are introduced by the tables LITETAB.RUN and LITETAB.PAR, respectively (see Figs. 24 and 25). For the shaded conditions (i.e., with the table LITETAB.RUN), the allochthonous input tables are SALLOC and FALLOC (see Fig. 2B); and for unshaded conditions (i.e., with the table LITETAB.PAR), WRSALOC and WRFALOC are used as the tables of allochthonous inputs (see Fig. 18B). In summary, shaded conditions are simulated by introducing the standard table of irradiation inputs and an allochthonous schedule that introduces 473 g m^{-2} of organic material per year, and open conditions are simulated by using the table of total irradiation inputs and an allochthonous schedule from the Willamette River that introduces 211 g m^{-2} organic material per year.

The parameters under investigation for each of the two irradiation/allochthonous schedules are the algal refuge parameter ($\mathbf{b}_{72}$), the minimum value for the food quality limiting factor ($\mathbf{b}_{121}$), and the assimilation efficiency parameter for shredders ($\mathbf{b}_{93}$). The effect of algal refuge is examined at four levels: 0.7, 4.0, 10.0, and 20.0 g m^{-2}, each for two values of $\mathbf{b}_{121}$ (0.28 and 0.80) and two values of $\mathbf{b}_{93}$ (0.18 and 0.30). Therefore, the simulation run design for this example problem is 4 x 2 x 2 = 16 runs for each of the two energy input schedules.

Twenty-five of the 32 simulation runs exhibit a one-year cycle; the other runs have either a 2-year or 4-year cycle (Table 5). Run 1 is the same as the standard run described on pages 106-107. Commands for Run 8 and Run 25 are listed below as examples of the procedures necessary to complete the series of simulation runs listed in Table 5.

Table 5. Proposed simulation runs for the investigation of the effects of irradiation, algal refuge, food quality, and shredder assimilation efficiency on biological processes in a simulated stream ecosystem.

Run	Cycle	Light	b(72)	b(121)	b(93)
1	1 year	shaded	0.70	0.28	0.18
2	1 year	shaded	0.70	0.28	0.30
3	1 year	shaded	0.70	0.80	0.18
4	1 year	shaded	0.70	0.80	0.30
5	1 year	shaded	4.00	0.28	0.18
6	1 year	shaded	4.00	0.28	0.30
7	1 year	shaded	4.00	0.80	0.18
8	1 year	shaded	4.00	0.80	0.30
9	4 year	open	0.70	0.28	0.18
10	1 year	open	0.70	0.28	0.30
11	4 year	open	0.70	0.80	18.00
12	1 year	open	0.70	0.80	0.30
13	1 year	open	4.00	0.28	0.18
14	1 year	open	4.00	0.28	0.30
15	1 year	open	4.00	0.80	0.18
16	1 year	open	4.00	0.80	0.30
17	1 year	shaded	10.00	0.28	0.18
18	1 year	shaded	10.00	0.28	0.30
19	1 year	shaded	10.00	0.80	0.18
20	1 year	shaded	10.00	0.80	0.30
21	1 year	shaded	20.00	0.28	0.18
22	1 year	shaded	20.00	0.28	0.30
23	1 year	shaded	20.00	0.80	0.18
24	1 year	shaded	20.00	0.80	0.30
25	4 year	open	10.00	0.28	0.18
26	2 year	open	10.00	0.28	0.30
27	2 year	open	10.00	0.80	0.18
28	1 year	open	10.00	0.80	0.30
29	4 year	open	20.00	0.28	0.18
30	1 year	open	20.00	0.28	0.30
31	2 year	open	20.00	0.80	0.18
32	1 year	open	20.00	0.80	0.30

To generate output for Run 8, type

C:\MODEL\RIPAR>**riparian**	(return)
CMD>**read=riparian.cmd**	(return)
CMD>**level=1**	(return)
CMD>**ib(72)=4.0**	(return)
CMD>**ib(121)=0.8**	(return)
CMD>**ib(93)=0.3**	(return)

Note: The command file is setup for the Standard Run and therefore specifies LITETAB.RUN, SALLOC, and FALLOC as the irradiation and allochthonous inputs. These are the correct tables for Run 8, which is one of the runs that simulates shaded conditions.

CMD>**tstop=7200**	(return)
CMD>**sint=360**	(return)
CMD>**run**	(return)
(Write down state variables values for day 7200)	(return)
CMD>**reset**	(return)
CMD>**tstop=360**	(return)
CMD>**sint=15**	(return)
CMD>**sset=x(2:7, 15:17)**	(return)
CMD>**ix(2:9)=.866,4.546,.482,27.898,.541,7.588,37.209,1.414**	(return)
CMD>**ix(10:14)=.225,30.851,1.145,16.978,.668**	(return)
CMD>**ix(15:17)=7.049,.756,.101**	(return)
CMD>**dfile=run8.dmp**	(return)

CMD>**dset=x(2:7,15:17)** (return)

CMD>**dint=1** (return)

CMD>**run** (return)

CMD>**q** (return)

This set of commands determines steady state values for the state variables and executes a one-year simulation run under steady state conditions. This run will produce: (1) the usual output or pfile, which is given the name RIP.OUT in the command file; and (2) a dump file (RUN8.DMP) that contains state variable values for the major processes and algal functional groups at a time resolution of one day. For this example, the data in RUN8.DMP was imported into the program SIGMAPLOT and the state variable trajectories were plotted to produce Figure 26.

To generate energy budget tables for Run 8, type

C:\MODEL\RIPAR>**ripartab** (return)

CMD>**read=ripartab.cmd** (return)

CMD>**level=1** (return)

CMD>**ib(72)=4.0** (return)

CMD>**ib(121)=0.8** (return)

CMD>**ib(93)=0.3** (return)

CMD>**ix(2:9)=.866,4.546,.482,27.898,.541,7.588,37.209,1.414** (return)

CMD>**ix(10:14)=.225,30.851,1.145,16.978,.668** (return)

CMD>**ix(15:17)=7.049,.756,.101** (return)

CMD>**run** (return)

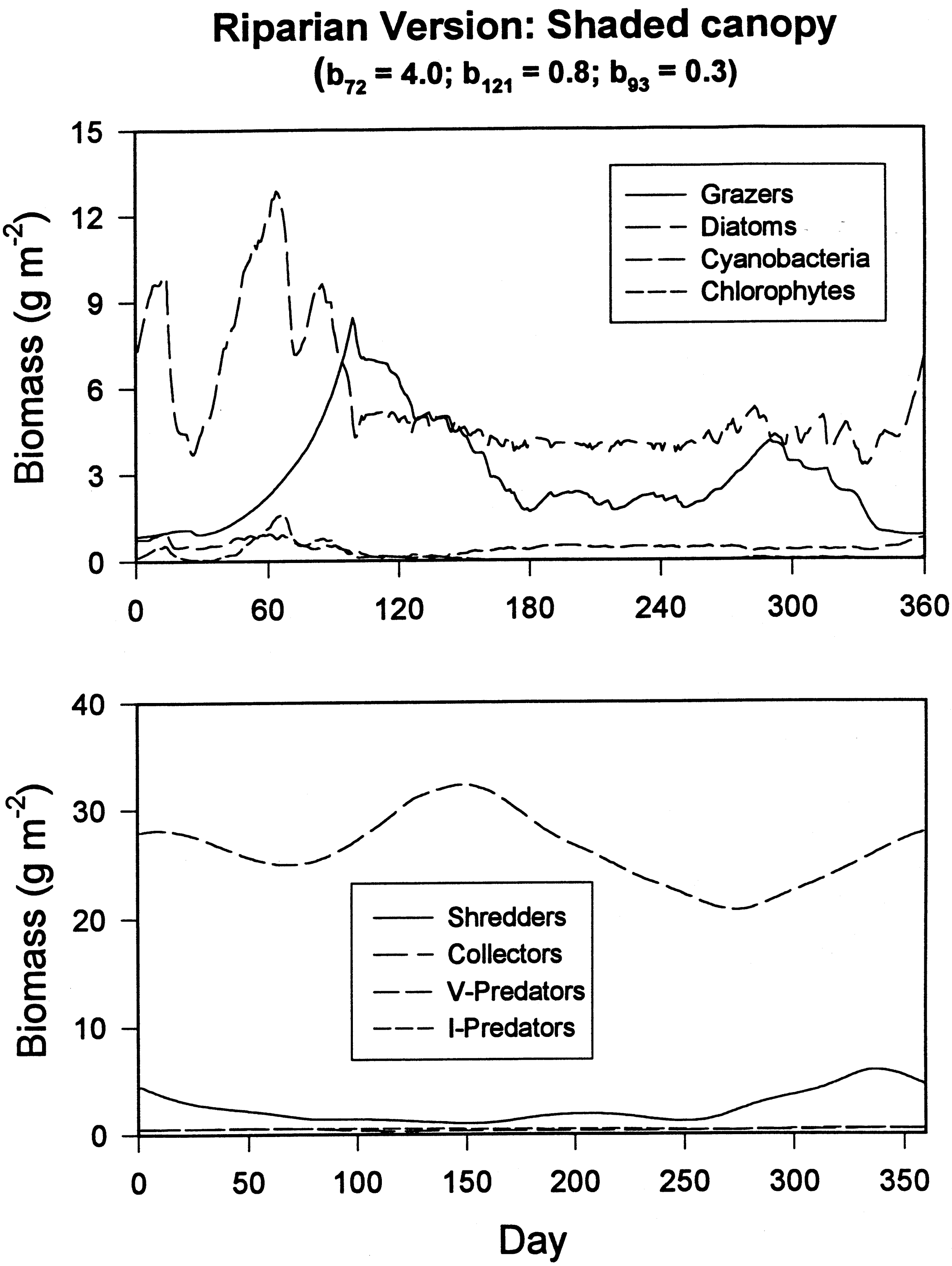


Figure 26. Seasonal dynamics of state variables representing the major biological processes in the Riparian Version of the M & C Stream Model. The run conditions are: shaded canopy, $b_{72} = 4$, $b_{121} = 0.8$, $b_{93} = 0.3$.

CMD > **q** (return)

C:\MODEL\RIPAR > **budget** (return)

After the prompt: "Please enter the simulation run number", type

(space) **Shaded: b(72)=4; b(121)=.8; b(93)=.3** (return)

After program execution is completed, type

C:\MODEL\RIPAR > **print stream.tab** (return)

C:\MODEL\RIPAR > **del stream.dmp** (return)

The last two commands will print out a copy of the energy budget tables that are stored in the file STREAM.TAB and then delete the dump file STREAM.DMP, which is produced by the program RIPARTAB.COM for the calculation of the values in the energy budget tables. Usually, STREAM.DMP is a relatively large file and is no longer needed after the execution of BUDGET.COM.

As a second example of one of the runs in Table 5, the commands for Run 25 are outlined below. Run 25 simulates effects of an open canopy (full sunlight) and an algal refuge of 10 g m^{-2}. Before Run 25 can be initiated, three changes in the command file RIPARIAN.CMD must be made in order to introduce the correct tables for irradiation and allochthonous inputs. In this case, the table of irradiation inputs LITETAB.RUN must be changed to LITETAB.PAR, and the tables of allochthonous inputs SALLOC and FALLOC are changed to WRSALOC and WRFALOC, respectively. The easiest way to do this is to use the DOS editor and change lines 27, 28, and 41 in the table listed on page 103.

After the changes are made in RIPARIAN.CMD, type

C:\MODEL\RIPAR > **riparian** (return)

CMD > **read=riparian.cmd** (return)

CMD > **level=1** (return)

CMD > **ib(72)=10.0** (return)

CMD > **ib(121)=0.28** (return)

CMD > **ib(93)=0.18** (return)

CMD > **tstop=14400** (return)

Note: Run 25 produces a 4-year cycle and requires a longer time period to converge to a constant set of initial conditions.

CMD > **sint=360** (return)

CMD > **run** (return)

(Write down state variables values for day 14400) (return)

CMD > **reset** (return)

CMD > **tstop=1440** (return)

CMD > **sint=15** (return)

CMD > **sset=x(2:7, 15:17)** (return)

CMD > **ix(2:9)=.698,.696,.683,17.479,.558,12.805,5.487,92.091** (return)

CMD > **ix(10:14)=2.661,14.527,.114,4.847,6.681E-2** (return)

CMD > **ix(15:17)=11.96,1.439,.654** (return)

CMD > **dfile=run25.dmp** (return)

CMD > **dset=x(2:7,15:17)** (return)

CMD > **dint=1** (return)

CMD > **run** (return)

CMD>**q** (return)

Plots of the six major state variables for the 4-year cycle are presented in Figure 27. To generate the corresponding energy budget tables for Run 25, type

C:\MODEL\RIPAR>**ripartab** (return)

CMD>**read=ripartab.cmd** (return)

CMD>**level=1** (return)

CMD>**ib(72)=10.0** (return)

CMD>**ib(121)=0.28** (return)

CMD>**ib(93)=0.18** (return)

CMD>**ix(2:9)=.698,.696,.683,17.479,.558,12.805,5.487,92.091** (return)

CMD>**ix(10:14)=2.661,14.527,.114,4.847,6.681E-2** (return)

CMD>**ix(15:17)=11.96,1.439,.654** (return)

CMD>**tstop=1440** (return)

CMD>**run** (return)

CMD>**q** (return)

C:\MODEL\RIPAR>**bud4yr** (return)

After the prompt: "Please enter the simulation run number", type

(space) **Open: b(72)=10; b(121)=.28; b(93)=.18** (return)

After program execution is completed, type

C:\MODEL\RIPAR>**print stream.tab** (return)

C:\MODEL\RIPAR>**del stream.dmp** (return)

Output from the 32 simulation runs predicts complex patterns of interaction among the

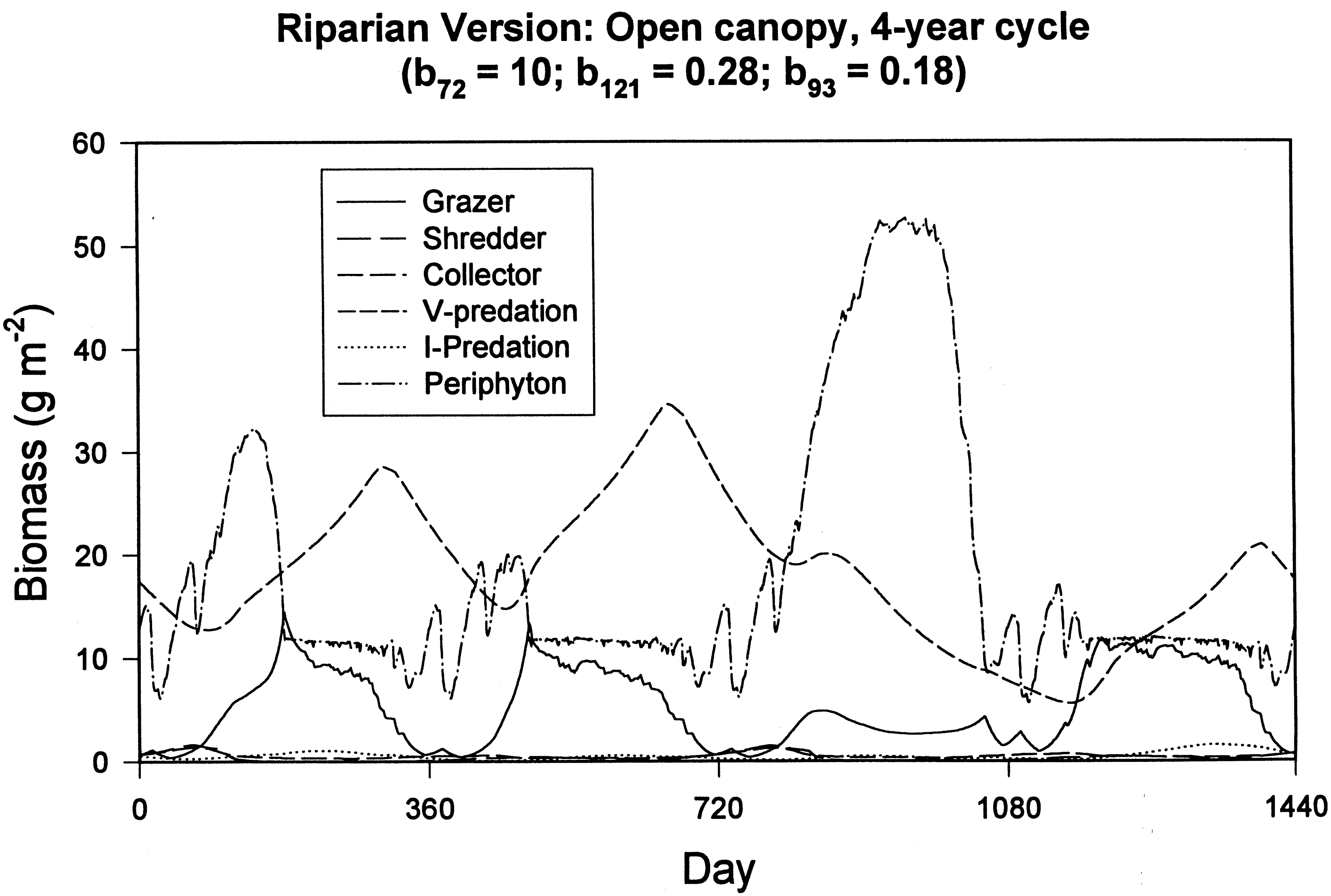
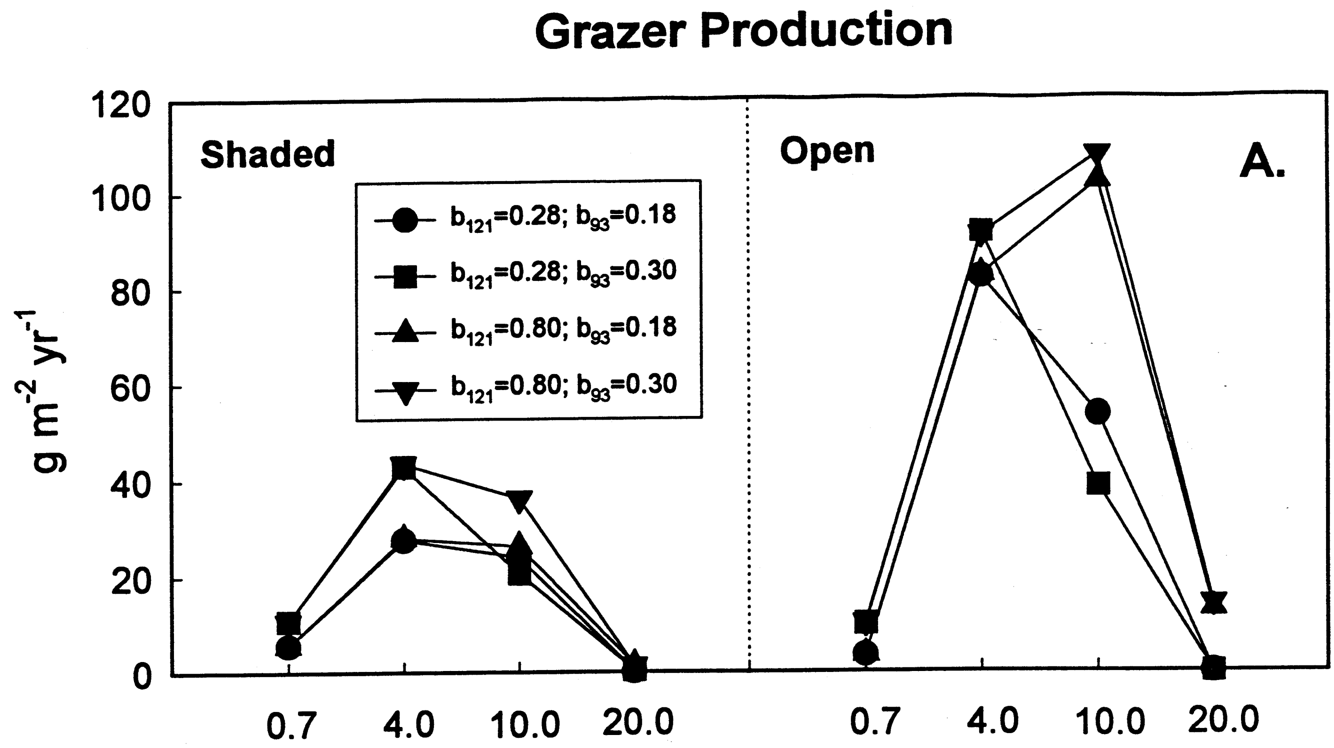


Figure 27. Seasonal dynamics of state variables representing the major biological processes in the Riparian Version of the M & C Stream Model. The run conditions are: open canopy, $b_{72} = 10$, $b_{121} = 0.8$, $b_{93} = 0.18$.

major biological processes represented by the model and between physical processes and the corresponding biological system. Here, output is presented and discussed in relation to the annual production rates associated with the processes of grazing, shredding, collecting, vertebrate predation, invertebrate predation, and primary production (Figs. 28, 29, and 30). If the user completes the entire series of simulation runs, analysis of the output can be extended to include some of the other variables listed in the print files and energy budget tables.

Model output predicts that grazer production is relatively low at algal refuges of 0.7 and 20.0 g m^{-2} (Fig. 28A), a pattern that corresponds to overgrazing (0.7 g m^{-2}) and extreme protection of the algal food resource (20 g m^{-2}). Shredder production is enhanced considerably by increasing the assimilation efficiency from 0.18 to 0.30 (Fig. 28B). The effect is more pronounced under shaded conditions, because the allochthonous input for the shaded system is over twice the input introduced for the simulation of the open canopy. Moreover, at an assimilation efficiency of 0.30, shredder production is higher at algal refuges of 4.0 and 10.0 g m^{-2} than at refuge levels of 0.7 and 20.0 g m^{-2}. Mechanisms that explain this pattern are not intuitively obvious and are related to complex trophic interactions between predators and the functional groups of primary consumers. More insight into such mechanisms can be obtained by examining plots of the specific growth rates discussed on pages 26 - 40 in relation to plots of the corresponding state variables.

The model predicts that the annual production dynamics of vertebrate predators are more tightly coupled to patterns of grazer production than to the annual production of either shredders or collectors (Figs. 28A, 29A, and 29B). The relatively high assimilation efficiency that is assumed for grazers (0.55) accounts, in part, for this pattern. With energy inputs that



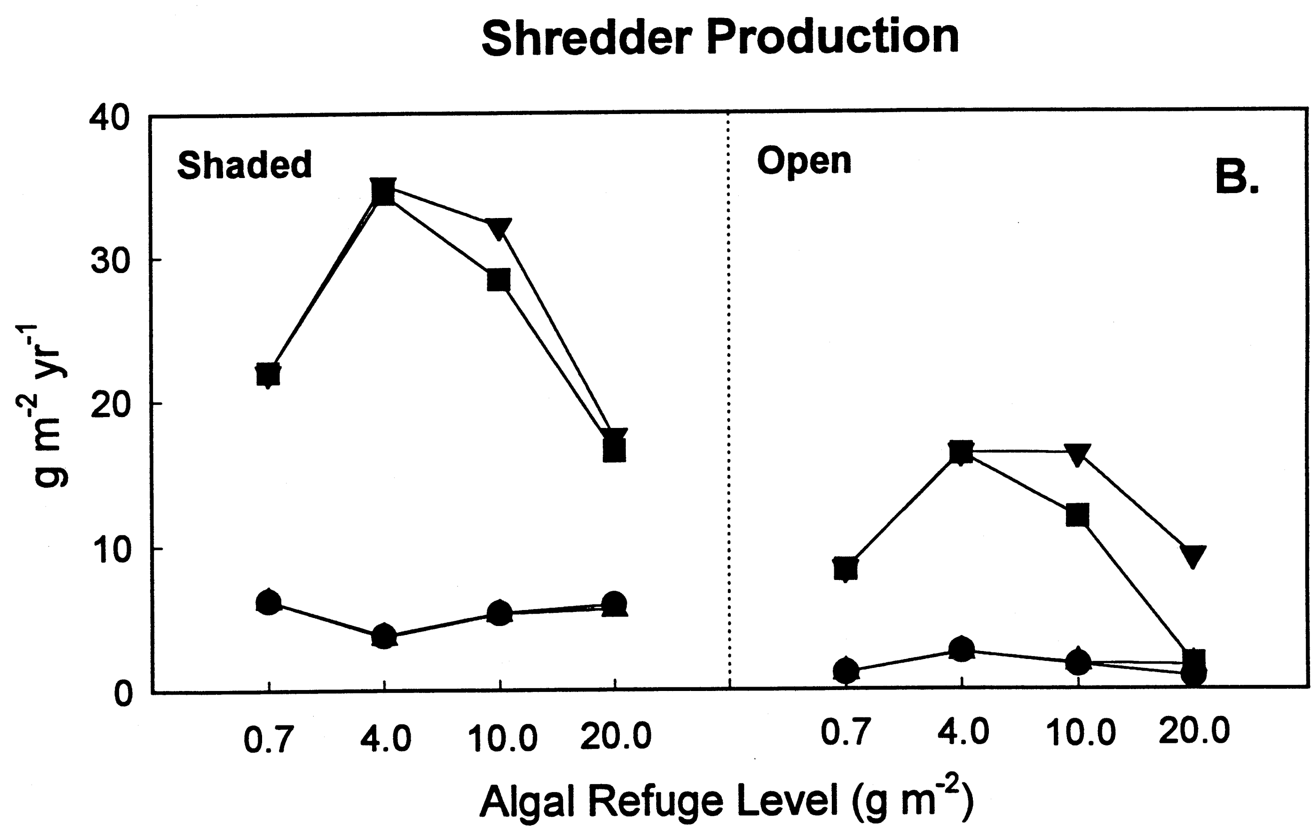


Figure 28. Relationships between annual grazer (A) and shredder (B) production and algal refuge level for a shaded and open forest canopy and two levels of food quality and shredder assimilation.

correspond to the shaded canopy, collector production is highest when the algal refuge is 0.7 and 20.0 g m^{-2}, refuge levels that generate the lowest grazer and vertebrate predator production. In this case, collector production is highest when predator pressure is lowest because of low grazer production and biomass, the primary food resource for invertebrate and vertebrate predators. Invertebrate predator production responds differently to changes in the selected parameters than annual rates of vertebrate production (Figs. 29B and 30A). Because invertebrate predators are also a food resource for vertebrate predators, invertebrate predator production is higher when shredder assimilation efficiency is 0.30 than when the value is 0.18 at the lowest algal refuge level (0.7 g m^{-2}). In this case the model predicts, that invertebrate predators are able to take advantage of the enhanced shredder production and biomass when overgrazing keeps grazer and vertebrate predator production at low levels. This pattern is apparent in both the shaded and open canopy simulations.

In summary, annual production rates obtained from the 32 simulation runs clearly indicate that complex, indirect relationships between biological processes and their corresponding functional groups can exist in stream systems, some of which are counterintuitive and not immediately obvious from field observations. Therefore, model output provides a good basis for hypothesis generation and the design of field and laboratory experiments that are relevant to the understanding of such complexities. Without modeling, interesting questions that relate to indirect relationships are not always apparent from the analysis of either experimental data or observational data from the field.

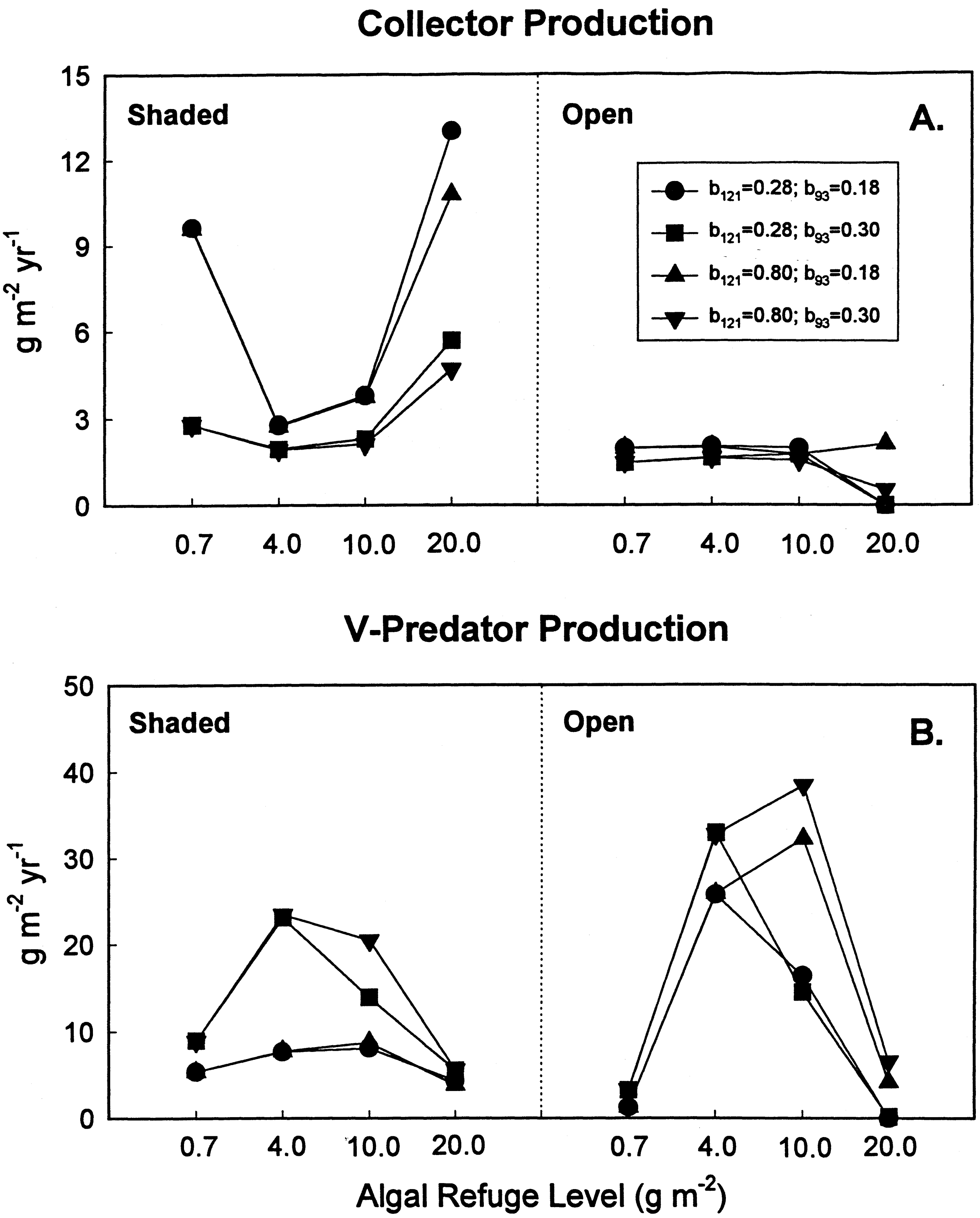
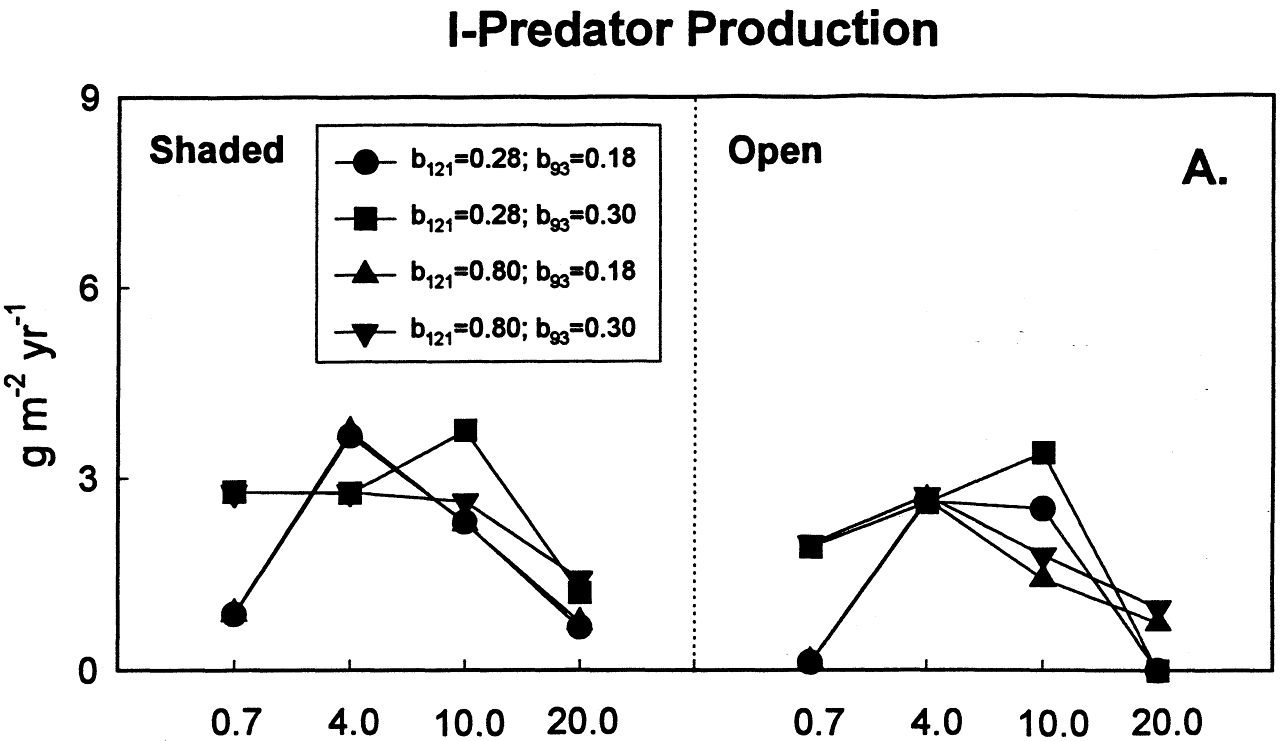


Figure 29. Relationships between annual collector (A) and vertebrate predator (B) production and algal refuge level for a shaded and open forest canopy and two levels of food quality and shredder assimilation.



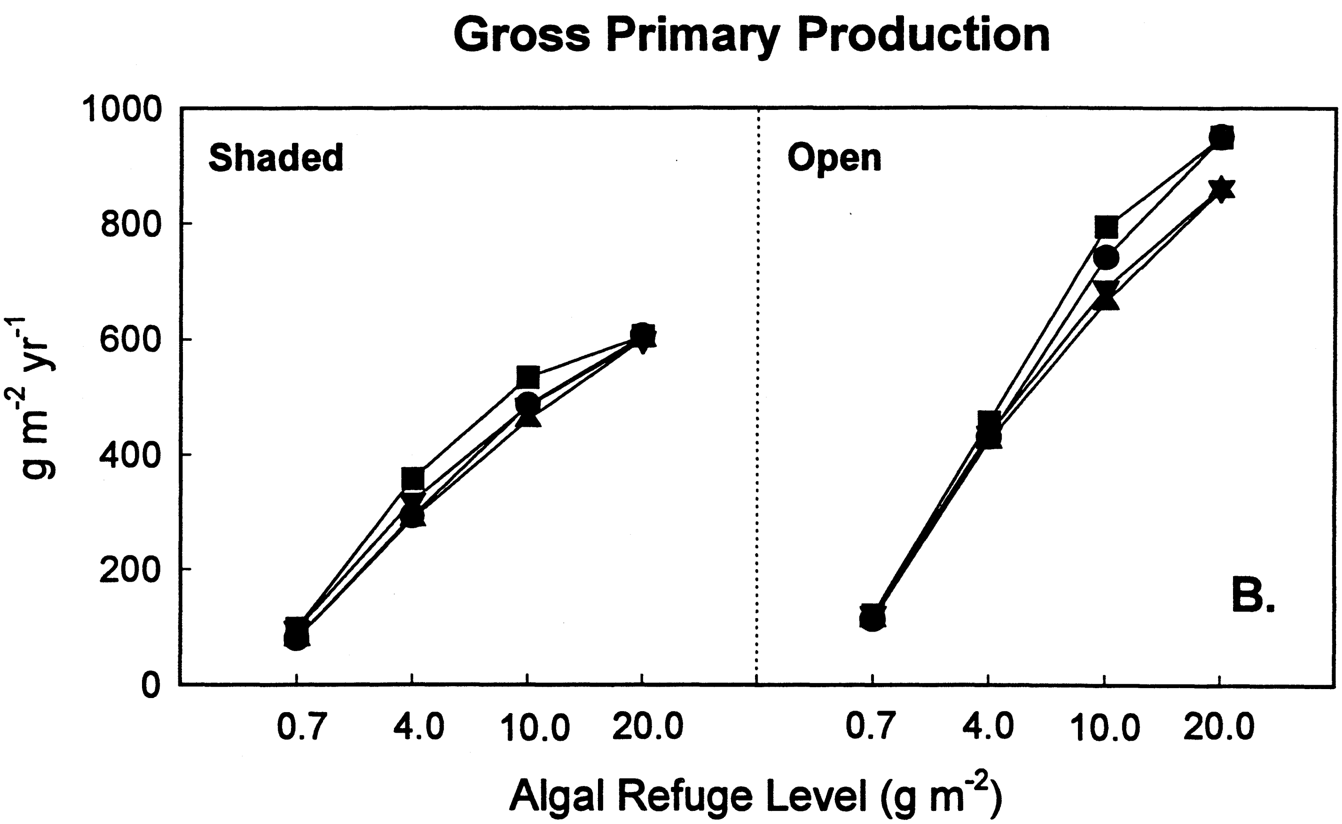


Figure 30. Relationships between annual invertebrate predator (A) and primary (B) production and algal refuge level for a shaded and open forest canopy and two levels of food quality and shredder assimilation.

DISCUSSION AND CONCLUSIONS

Simulation output from the three versions of the M & C Stream Model provides examples of the kinds of insights and research directions that modeling can provide. It is interesting to note that we often learn more when model output is inconsistent with reality than when trajectories of state variables are similar to what we observe in nature. In some cases, nothing succeeds like failure, because when the model does not exhibit the expected or desired behavior, its current structure represents an explicit expression of ignorance that can be analyzed and evaluated for the purpose of setting priorities for future research. Often, reevaluation of model structure in relation to its current behavior generates new ways of thinking about the system under investigation. In the examples presented in the earlier sections of this tutorial, model behavior suggests that we can learn a great deal from studies that examine direct, and particularly the indirect, relationships between the primary producers and the primary and secondary consumers in lotic ecosystems. These kinds of studies are much more difficult to design than studies that focus on individual taxa or assemblages of taxa in isolation.

Modeling also provides a basis for partitioning ecological processes into their component parts. Simulation runs from the M & C stream model are performed by the FLEX model processor (Overton, 1972, 1975) and are based on a discrete time increment of one day. The update algorithm is a simple difference equation,

$$\mathbf{x}(k + 1) = \mathbf{x}(k) + \Delta(k) \tag{1}$$

where $\mathbf{x}$ is a vector of state variable values at time k, $\mathbf{x}(k + 1)$ is a vector of values for the same variables one day later, and $\Delta(k)$ is a vector of the net changes in $\mathbf{x}$ between time k and k + 1 estimated at time k. In the case of primary consumers (grazers, shredders, and collectors),

$$\Delta_i = a_i C_i - R_i - E_i - M_i - P_i \qquad (2)$$

where C is the food consumed between k and k + 1; R, E, M, and P are corresponding losses to respiration, emergence and export, natural mortality, and predation, respectively; and a is the assimilation efficiency. In order to understand how the system works, each of the components of Δ_i must be investigated. Moreover, components at this level are functions of other variables and can be partitioned into sets of subcomponents. In the examples presented earlier in the tutorial, consumption of algal biomass by grazers is a function of food demand and a food density limiting factor, which itself is a function of the algal biomass minus the algal refuge level. Food demand is a function of temperature and is adjusted by the food quality limiting factor.

The value of partitioning ecological processes into their component parts goes beyond the exercise of creating a mathematical model. The identification of process components requires a fundamental understanding of the process and provides an explicit set of variables for research purposes and review. Furthermore, the definition of process components can lead to useful ecological concepts that can serve as a basis for experimental design and hypothesis testing. Examples of such concepts from the M & C stream model include: (1) food demand, the consumption of a food resource when the supply is unlimited; (2) algal refuge, the algal biomass below which consumption by macroconsumers is zero; and (3) the food quality limiting factor, a value that adjusts the food demand to the quality of the food resource. All three of these concepts can be incorporated into hypotheses and the design of future field and laboratory experiments.

Output from the M & C stream model clearly demonstrates that links between resource production and consumption are altered by access to the resource. Availability of algal resources in the model is controlled by both physical and biological factors. Substrate heterogeneity and elevation of algal growth forms above the substrate surface are physical characteristics that modify the outcome of grazer-periphyton interactions, whereas biological features that alter the access of herbivores to food resources include food quality, morphology of mouthparts and food-gathering structures, and behavioral patterns. In the M & C model, the algal refuge parameter and a parameter that controls the food quality limiting factor affect food availability, consumption, and assimilation. Both of these parameters have a strong effect on the behavior of the Herbivory subsystem of the model, and as a result, have the capacity to change the production of other components of the system that are indirectly linked to the process of herbivory. Studies of herbivory in streams usually are based on an unstated assumption that 100% of the plant biomass is available to herbivores. However, it is unlikely that this assumption is consistent with the structural and functional attributes of most natural streams. The stream model predicts that biological components in natural streams are sensitive to resource availability and indicates that different patterns of herbivory could be observed in seemingly similar systems.

One of the more interesting hypotheses generated by the behavior of the M & C Stream Model suggests that dynamics of vertebrate predator populations may be tightly coupled to patterns of benthic primary production when conditions are favorable for the growth of the algal food resource. If this is really true, indirect relationships between vertebrate predators and benthic algae have management implications in fisheries. If the hypothesis is false, or when it is false, it would be interesting to know why the natural system exhibits behavior that is counter to the outcome predicted by bioenergetic considerations. In streams, periodic dominance of physical factors in interaction with peculiarities of the life history characteristics of individual taxa may cause deviations from patterns predicted by models in which such details are not represented at the process level of organization. Therefore, model output can sometimes indicate when it is appropriate to do the research necessary to elaborate the structure of the model subsystems in greater detail. The expansion of the Herbivory subsystem of the M & C Stream Model illustrates how a new set of research objectives can require the development of new model structures and concepts at a finer level of resolution.

Mathematical modeling also can be used to address some of the broader, more theoretical aspects of stream ecology. As an example, we consider the question of whether stream ecosystems are controlled by "bottom-up" or "top-down" processes and how the dynamics of the different functional groups of organisms relate to this question. In stream ecology, "top-down" control usually refers to a case when an increase in a resource that limits primary production (e.g., light energy or nutrients) has no effect on algal biomass, because autotrophic biomass is controlled by grazers (Steinman, 1992; Rosemond *et al.*, 1993). In contrast, "bottom-up" control means that algal biomass increases significantly with an increase in the input of some limiting factor. Some of the ambiguities about "top-down" and "bottom-up" mechanisms relate to what is actually meant by control and whether the focus is on an individual population, a functional group, or the ecosystem as a whole. For example, the M & C stream model predicts that under some conditions, an increase in the level of a limiting factor can enhance primary production without a conspicuous change in algal biomass, because the biomass turns over more rapidly in response to the increase in resources and concurrent increases in macroconsumer production and biomass. Consequently, "bottom-up" control is achieved without much change in the mean algal biomass. This indicates that it might be less ambiguous to define limitation or control in terms of production instead of biomass. However, in the case of streams, which often obtain their resources from both autochthonous and allochthonous sources, an increase in detrital inputs from the surrounding terrestrial environment will always result in an increase in energy flux through the ecosystem ("bottom-up" control) regardless of the effects of predators on primary consumers. In other words, if shredders and collectors do not process the new material, it will ultimately be processed by the microbial flora. The pronounced seasonality of allochthonous and autochthonous inputs and the frequent disturbance regimes in stream ecosystems make it unlikely that simple "top-down" or "bottom-up" effects would occur throughout a food web. Instead, controls are likely to be transient, and the complex array of life histories and generation times characteristic of lotic ecosystems tend to obscure mechanisms of control and patterns of resource limitation and exploitation.

Experience with the M & C Stream Model suggests a more direct approach to the understanding of process limitation and control. Modeling for research purposes often requires that each process be partitioned into its component parts (see equation 2), each part of which represents either a gain or loss to the associated state variable. Therefore, mechanisms of regulation and control are revealed by the relative importance of the positive or negative effects of each part on the process. McIntire and Colby (1978) and McIntire (1983) defined a new set of variables that allow a graphic display of the factors that prevent a state variable from reaching its maximum potential specific growth rate (see pages 26-40 of this tutorial). For example, model output predicts that in a shaded stream receiving relatively high allochthonous inputs (473 g m^{-2} yr^{-1}), the process of grazing is controlled by the algal food resource, whereas the processes of shredding and collecting are affected more by predation than by resource limitation (see Figs. 4A, 4B, and 5A). Model output also indicated that it is possible for such control to vary seasonally and that at certain times physical processes or losses relating to life history characteristics (e.g., emergence) may have much greater effects on process dynamics than trophic interactions.

In summary, theoretical generalizations can evolve from a systematic investigation of different model structures, while varying inputs and parameters. Experimental and observational studies of biological processes in streams provide the data base necessary for a modeling approach to the synthesis of existing information and concepts into an integrated theory of how functional groups of organisms relate to each other and to physical processes in lotic ecosystems. In particular, modeling is a powerful research tool when it is used in close association with related laboratory and field studies.

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APPENDIX I

MATHEMATICAL DOCUMENTATION FOR THE M & C STREAM MODEL: VERSION I

Introduction

Appendix I provides a detailed mathematical description of Version I of the M & C Stream Model. Model structure conforms to the FLEX paradigm (Overton, 1972, 1975) which is implemented by the program FLEX, a general model processor programmed for IBM compatible personal computers. The mathematical structure of the Version I of the model evolved during a 6-year period (1971-1976); and with the exception of the periphyton module, most of the modeling was done between 1973 and 1976 at Oregon State University. Subsequent versions of the model, including the Riparian Version and Herbivory Version, were developed between 1985 and 1994. The original mathematical documentation for Version I was in the FLEXFORM format (White and Overton, 1974) and was prepared during the fall of 1976. The FLEXFORM for this version of the model was revised by Curtis White in October of 1977 and was made available as Internal Report 165, Coniferous Forest Biome (Colby and McIntire, 1978). The documentation in this section of the tutorial is mathematically similar to White's revision, and is put into a format more suitable for researchers and students not familiar with the FLEX paradigm and its working technical document, the FLEXFORM. Although the uncompiled FLEX model processor is not available to the general public, documentation in this section is sufficient to allow modifications of the model to be generated in any appropriate programming language.

Definition of System Variables

The definition and notation for system variables in the mathematical documentation of all versions of the M & C Stream Model follow the FLEX convention. Symbols used in the documentation are x (state variables), z (input variables), g (intermediate or interaction variables), y (output variables), f (update increments for state variables), and b (parameters). In addition, the command file requires specification of memory variables (m). In the model versions described in this tutorial, m variables are used to calculate special output variables that can be used to help interpret state variable dynamics.

State variables (x) are the instantaneous values of the system outputs, usually the collective biomasses of groups of organisms involved in various biological processes (e.g., grazing, shredding, and collecting). Input variables (z) are introduced as a constant, a time-varying algebraic function, or a table look-up. For example, in Version I of the model, stream temperature, light energy inputs, nutrient concentrations, stream flow, and allochthonous inputs are introduced by table look-up, whereas stream depth, width, and cross-sectional area are power functions of stream flow. Simulation runs from all versions of the M & C Stream Model are based on a discrete time increment of one day. The update algorithm is a simple difference equation,

$$\mathbf{x}(k + 1) = \mathbf{x}(k) + \Delta(k) \quad ,$$

where $\mathbf{x}(k)$ is a vector of state variable values at time k, $\mathbf{x}(k + 1)$ is a vector of values for the same variables one day later, and $\Delta(k)$ is a vector of the net changes in $\mathbf{x}$ between time k and $k + 1$ estimated at time k. In the documentation, Δ values are calculated as f functions. For example, the update increment for the grazer biomass is f_2, and f_2 is calculated from :

$$f_2 = b_{92} g_{51} - g_1 - g_3 - g_4 \quad ,$$

where

b_{92} = the grazer assimilation efficiency (0.55 for the Standard Run);

g_{51} = the food consumption by grazers;

g_1 = grazer respiratory losses;

g_3 = grazer emergence losses; and

g_4 = grazer biomass losses to predators.

In this case, the *g* variables represent the interaction or intermediate variables necessary to calculate the update increments (*f*). Examples of other g variables are periphyton respiration, periphyton primary production, export of fine particulate organic matter, and the consumption of invertebrate predator biomass by vertebrate predators. In Version I of the model, *g* variables are functions of state variables (*x*), input variables (*z*), other *g* variables, and relevant parameters (*b*); whereas update variables (*f*) are functions of *g* variables, state variables (*x*), and parameters (*b*).

Output variables (*y*) for Version I of the model are set to equal state variables (*x*) or the summation of state variables. In addition, some special output variables are available to the user to aid in the interpretation of state variable dynamics. These special output variables are a function of *g* variables, other *y* variables, memory variables (*m*), and parameters (*b*). The definition and use of special output variables are discussed on pages 26-40 of this tutorial and by McIntire (1983).

In the original documentation of Version I of the model (Colby and McIntire, 1978), parameters were specified by the letters *b* or *r*, but in the documentation presented in this section, all parameters are designated by the *b* notation. Values for parameters used in the Standard Run (Section 6, page 187) were obtained by estimation procedures or from the literature. For more detail concerning the biological basis for these values, the reader may refer to McIntire (1973) and McIntire and Colby (1978).

Mathematical Documentation

TITLE:	McIntire and Colby Stream Model: Version I
INVESTIGATORS:	C. David McIntire and Jonathon A. Colby
DATE:	December 1976
REVISED BY:	C. David McIntire
REVISION DATE:	September 1995
TIME RESOLUTION:	1 day (360 days = 1 year)
QUANTITY MODELED:	Biomass expressed as organic matter (dry weight)

VARIABLES AND FUNCTIONS:

1.

X List	Description	Units
x_1	Not used	-
x_2	Grazer biomass	g m^{-2}
x_3	Shredder biomass	g m^{-2}
x_4	Collector biomass	g m^{-2}
x_5	Vertebrate predator biomass	g m^{-2}
x_6	Invertebrate predator biomass	g m^{-2}

x_7	Periphyton biomass	g m^{-2}
x_8	Fine particulate organic matter biomass (FPOM)	g m^{-2}
x_9	Conditioned allochthonous biomass - slow rate (CSLPOM)	g m^{-2}
x_{10}	Conditioned allochthonous biomass - fast rate (CFLPOM)	g m^{-2}
x_{11}	Unconditioned allochthonous biomass - slow rate (SLPOM)	g m^{-2}
x_{12}	Unconditioned allochthonous biomass - fast rate (FLPOM)	g m^{-2}
x_{13}	SLPOM conditioning gate	none
x_{14}	FLPOM conditioning gate	none

2. Z Functions (input functions):

	Description	Units
z_1 = table choice: STRTEMP if $b_4 < 0$, otherwise b_4	Water temperature	°C

Note: In a developmental stage of Version I of the model, z_1 was represented by the equation:

$$z_1 = b_4 + b_5 \sin\left(\frac{2\pi k}{360} - \frac{\pi}{2}\right) ,$$

where b_4 and b_5 are equal to 12 and 6, respectively, and k is the number of days from the first of the year.

z_2 = table choice: EXLITE if $b_{113} < 0$, otherwise b_{113}	Light intensity directly above stream	ft-c
z_3 = table choice: XNUTR if $b_{111} < 0$, otherwise b_{111}	Nutrient concentration	mg l^{-1}
z_4 = table choice: STRFLOW if $b_{112} < 0$, otherwise b_{112}	Stream flow	cfs
z_5 = table choice: SALLOC if $b_{114} < 0$, otherwise b_{114}	Allochthonous input (slow conditioned)	g m^{-2}
z_6 = table choice: FALLOC if $b_{104} < 0$, otherwise b_{104}	Allochthonous input (fast conditioned)	g m^{-2}
$z_7 = b_8(b_{11} + b_{10} z_4 + b_9 z_4^2 + z_4^3)$,	Suspended load	mg l^{-1}

	Description	Units
where $b_8 = 1.97 \times 10^{-4}$, $b_9 = -94.4$, $b_{10} = 9.42 \times 10^{3}$, $b_{11} = 1.08 \times 10^{3}$.		
$z_8 = b_{12} z_4^{-b_{13}}$, where $b_{12} = 4.88 \times 10^{-2}$, $b_{13} = 8.83 \times 10^{-2}$.	Roughness coefficient	none
$z_9 = b_{16} z_4^{b_{17}}$, where $b_{16} = 1.07$, $b_{17} = 0.633$.	Stream cross-sectional area	ft^2
$z_{10} = b_6 z_4^{b_7}$, where $b_6 = 0.114$, $b_7 = 0.581$.	Stream depth	ft
$z_{11} = b_{14} z_4^{b_{15}}$, where $b_{14} = 10.2$, $b_{15} = 2.95 \times 10^{-3}$.	Stream width	ft
$z_{12} = \dfrac{z_9}{2z_{10} + z_{11}}$,	Hydraulic radius	ft

	Description	Units

where

z_9 = cross-sectional area,

z_{10} = stream depth,

z_{11} = stream width.

$$z_{13} = \frac{45.42 z_{12}^{\frac{2}{3}} b_2^{\frac{1}{2}}}{z_8} ,$$

Current velocity — cm sec^{-1}

where

b_2 = 0.0139, the channel slope,

z_8 = roughness coefficient,

z_{12} = hydraulic radius.

$$z_{14} = \min\left[1,\ 0.2 + \frac{b_3 z_{13}}{1 + b_3 z_{13}}\right] ,$$

Current velocity effect — none

where

b_3 = 0.057,

z_{13} = current velocity.

$$z_{15} = 304.73 b_2 z_{12} ,$$

Shear stress — kg m^{-2}

where

b_2 = 0.0139, the channel slope,

z_{12} = hydraulic radius.

$$z_{16} = z_2 \exp[-z_{10} 0.305 \min(3,\ \max(0.03,\ 0.03 z_7 + 0.2))] ,$$

Effective light intensity at stream bottom — ft-c

where

z_2 = the illumination intensity,

	Description	Units
z_{10} = stream depth,		
z_7 = suspended load.		
z_{17} = table choice: PHOTPER if $b_{43} < 0$, otherwise b_{43}	Photoperiod (hours of daylight per day)	hr

Note: In a developmental stage of Version I of the model, z_{17} was represented by the equation:

$$z_{17} = b_{43} + b_{44}\sin\left(\frac{2\pi k}{360} - \frac{\pi}{2}\right) ,$$

where b_{43} and b_{44} are equal to 12 *and* 4, *respectively, and k is the number of days from the first of the year.*

3. G Functions (intermediate functions):	Description	Units
$g_1 = x_2(b_{81} + b_{101}z_1)$,	Grazer respiration	g m^{-2}

where

b_{81} = 1.46×10^{-2},

b_{101} = 4.46×10^{-3},

z_1 = water temperature,

x_2 = grazer biomass.

$$g_2 = x_2 b_{100} \begin{cases} 0.046z_1 & \text{if } z_1 < 2, \\ 0.0268z_1 + 0.0388 & \text{if } 2 \le z_1 < 18, \\ -0.0435z_1 + 1.305 & \text{if } 18 \le z_1 < 30, \\ 0 & \text{if } z_1 \ge 30 \end{cases}$$

Grazer demand for periphyton — g m^{-2}

where

b_{100} = 1,

z_1 = water temperature,

x_2 = grazer biomass.

	Description	Units
$g_3 = x_2 b_{85}[\textit{table choice GEMER}]$,	Grazer emergence losses	$g\ m^{-2}$

where

b_{85} = 0.8, the scaling factor,

x_2 = grazer biomass,

GEMER is a table of daily emergence totals

$g_4 = g_{13}\max[0, (x_2 - b_{96})]$,	Loss of grazer biomass to predators	$g\ m^{-2}$

where

b_{96} = 0.3,

x_2 = grazer biomass,

g_{13} = the coefficient of predation on primary consumers.

$g_5 = x_3(b_{82} + b_{102}z_1)$,	Shredder respiration	$g\ m^{-2}$

where

b_{82} = 2.86 x 10^{-2},

b_{102} = 4.46 x 10^{-3},

z_1 = water temperature,

x_3 = shredder biomass.

$g_6 = x_3(1 + b_{89})b_{88}\min\left[\frac{1.2b_{99}z_1}{1 + b_{99}z_1}, 1\right]$,	Shredder demand for CSLPOM and CFLPOM	$g\ m^{-2}$

	Description	Units

where

b_{88} = 0.7,

b_{89} = 0.237,

b_{99} = 0.167,

z_1 = water temperature,

x_3 = shredder biomass.

$g_7 = x_3 b_{86}[\textit{table choice SEMER}]$, — Shredder emergence losses — g m^{-2}

where

b_{86} = 12,

x_3 = shredder biomass,

SEMER is a table of daily emergence totals

$g_8 = g_{13}\max[0, (x_3 - b_{97})]$, — Loss of shredder biomass to predators — g m^{-2}

where

b_{97} = 0.3,

x_3 = shredder biomass,

g_{13} = the coefficient of predation on primary consumers.

$g_9 = x_4(b_{83} + b_{103}z_1)$, — Collector respiration — g m^{-2}

where

b_{83} = 1.46 x 10^{-2},

b_{103} = 4.46 x 10^{-3},

z_1 = water temperature,

x_4 = collector biomass.

	Description	Units
$$g_{10} = x_4 \begin{Bmatrix} 0.12z_1 & \text{if } z_1 < 2, \\ 0.015z_1 + 0.21 & \text{if } 2 \le z_1 < 18, \\ -0.04z_1 + 1.2 & \text{if } 18 \le z_1 < 30, \\ 0 & \text{if } 30 \le z_1 \end{Bmatrix}$$	Collector demand for FPOM	g m^{-2}

where

z_1 = water temperature,

x_4 = collector biomass.

$g_{11} = x_4 b_{87}[\text{table choice } CEMER]$,	Collector emergence losses	g m^{-2}

where

b_{87} = 0.35, the scaling factor,

x_4 = collector biomass,

CEMER is a table of emergence totals.

$g_{12} = g_{13}\max[0, (x_4 - b_{98})]$,	Loss of collector biomass to predators	g m^{-2}

where

b_{98} = 0.3,

x_4 = collector biomass,

g_{13} = coefficent of predation on all primary consumers.

$$g_{13} = \begin{Bmatrix} 0 & \text{if } g_{21} \le 0, \\ \dfrac{g_{57} + g_{58}}{g_{21}} & \text{otherwise} \end{Bmatrix}$$	Coefficient of predation on all primary consumers	none

	Description	Units

where

g_{21} = primary consumer biomass available for consumption,

g_{57} = food consumption of primary consumers by invertebrate predators,

g_{58} = food consumption of primary consumers by vertebrate predators.

$$g_{14} = \begin{cases} \dfrac{b_{78} z_3}{1 + b_{78} z_3} & \text{if } z_3 < b_{68} \\ 1 - \left(\dfrac{1}{1 + b_{68} b_{78}}\right)\left(\dfrac{b_{69} - z_3}{b_{69} - b_{68}}\right) & \text{if } b_{68} \le z_3 < b_{69} \\ 1 & \text{if } b_{69} \le z_{16} \end{cases}$$

Nutrient limiting effect coefficient for primary production — none

where

b_{68} =1 x 10^{-3},

b_{69} = 0.5,

b_{78} = 2.68 x 10^{2},

z_3 = limiting nutrient concentration (NO_3^-).

$$g_{15} = \begin{cases} \dfrac{b_{71} z_{16}}{1 + b_{71} z_{16}} & \text{if } z_{16} < b_{90} \\ 1 - \left(\dfrac{1}{1 + b_{90} b_{71}}\right)\left(\dfrac{b_{91} - z_{16}}{b_{91} - b_{90}}\right) & \text{if } b_{90} \le z_{16} < b_{91} \\ 1 & \text{if } b_{91} \le z_{16} \end{cases}$$

Light limiting effect for primary production — none

where

b_{71} = 2.1 x 10^{-3},

b_{90} = 1 x 10^{3},

	Description	Units

b_{91} = 2.4×10^3,

z_{16} = effective light intensity at the stream bottom.

g_{16} *through* g_{18} — Not used

$$g_{19} = \max[0,\ x_6 - b_{50}]\ ,$$

Invertebrate predator biomass available for consumption by vertebrate predators — g m^{-2}

where

b_{50} = 0.3,

x_6 = invertebrate predator biomass.

$$g_{20} = (1 - b_{92})g_{51} + \left(1 - \frac{b_{93}}{1 + b_{89}}\right)g_{52} + (1 - b_{94})g_{53}\ ,$$

FPOM generated by primary consumption — g m^{-2}

where

b_{89} = 0.237, the fraction of consumption by shredders that represents mechanical transfer,

b_{92} = 0.55, assimilation ratio for grazers,

b_{93} = 0.18, assimilation ratio for shredders,

b_{94} = 0.21, assimilation ratio for collectors,

g_{51} = consumption of periphyton by grazers,

g_{52} = consumption of CSLPOM and CFLPOM by shredders,

g_{53} = consumption of FPOM by collectors.

	Description	Units

$$g_{21} = \max[0,\ x_2 - b_{96}] + \max[0,\ x_3 - b_{97}] + \max[0,\ x_4 - b_{98}] \ ,$$

Primary consumer biomass available for consumption by predation — g m^{-2}

where

b_{96} = 0.3,

b_{97} = 0.3,

b_{98} = 0.3,

x_2 = grazer biomass,

x_3 = shredder biomass,

x_4 = collector biomass.

$$g_{22} = x_6(b_{56} + b_{106}z_1) \ ,$$

Invertebrate predator respiration — g m^{-2}

where

b_{56} = 1.88×10^{-2},

b_{106} = 0,

z_1 = water temperature,

x_6 = invertebrate predator biomass.

$$g_{23} = x_6 b_{59} \min\left[\frac{1.2 b_{60} z_1}{1 + b_{60} z_1} \ ,\ 1\right] \ ,$$

Invertebrate predator demand for primary consumers — g m^{-2}

where

b_{59} = 0.05,

b_{60} = 100,

z_1 = water temperature,

x_6 = invertebrate predator biomass.

	Description	Units
$g_{24} = x_6 b_{57}[table\ choice\ PEMER]$,	Invertebrate predator emergence losses	g m^{-2}

where

b_{57} = 0.42, a scaling factor,

x_6 = the invertebrate predator biomass,

PEMER is a table of daily emergence totals.

$$g_{25} = b_{52}(g_{27} + g_{54} + g_{58}) + x_5(b_{53} + b_{105}z_1 + b_{54}) \ ,$$

	Description	Units
	Vetebrate predator mortality and respiration losses	g m^{-2}

where

b_{52} = 0.1,

b_{53} = 1.87 x 10^{-3},

b_{54} = 2.5 x 10^{-3},

b_{105} = 1.44 x 10^{-4},

x_5 = vertebrate predator biomass,

g_{27} = vertebrate predator demand for food,

g_{54} = vertebrate predation of drifting organisms,

g_{58} = vertebrate predation of primary consumer organisms.

	Description	Units
$g_{26} = x_5 b_{55}$,	Vertebrate predator demand for food	g m^{-2}

where

b_{55} = 2.6 x 10^{-2},

x_5 = vertebrate predator biomass.

	Description	Units
$$g_{27} = \begin{cases} 0 & \text{if } g_{19} \le 0 \\ g_{56}\left(\dfrac{g_{19}}{g_{19} + g_{21}}\right) & \text{otherwise} \end{cases},$$	Consumption of invertebrate predator biomass by vertebrate predators	g m^{-2}

where

g_{19} = invertebrate predator biomass available for consumption,

g_{21} = primary consumer biomass available for consumption,

g_{56} = vertebrate predator capacity to reduce primary consumer and invertebrate predator biomass.

$$g_{28} = (1 - b_{51})(g_{27} + g_{54} + g_{58}) + (1 - b_{58})g_{57} ,$$

	Description	Units
	FPOM generated by predation	g m^{-2}

where

b_{51} = 0.86,

b_{58} = 0.82,

g_{27} = consumption of invertebrate predator biomass by vertebrate predation,

g_{54} = consumption of drifting organisms by by vertebrate predation,

g_{58} = consumption of primary consumers by vertebrate predation,

g_{57} = consumption of primary consumers by invertebrate predators.

	Description	Units
$$g_{29} = \frac{b_{107} z_{14} x_7}{1 + e^{(1.7 - b_{80} z_1)}} ,$$	Periphyton respiration	g m^{-2}

where

b_{80} = 0.187,

b_{107} = 5.85 x 10^{-2},

z_1 = water temperature,

z_{14} = current velocity effect,

x_7 = periphyton biomass.

$$g_{30} = 0.937 b_{79} g_{31} g_{14} g_{15} z_{14} z_{17} ,$$	Periphyton primary production	g m^{-2}

where

b_{79} = 2.95,

g_{31} = biomass and temperature limiting effect coefficient,

g_{14} = nutrient limiting effect,

g_{15} = light limiting effect,

z_{14} = current velocity effect,

z_{17} = photoperiod.

$$g_{31} = \left(\frac{b_{76} x_7}{1 + b_{76} x_7} \right) \left(\frac{b_{77} z_1}{1 + b_{77} z_1} \right) ,$$	Biomass and temperature limiting effects on primary production	none

where

b_{76} = 0.1,

b_{77} = 0.4,

z_1 = water temperature,

x_7 = periphyton biomass.

	Description	Units
$g_{32} = x_7(b_{75} + b_{70}z_{15})$,	Fine particle periphyton export	g m^{-2}

where

b_{75} = 1.08 x 10^{-3},

b_{70} = 1.92 x 10^{-2},

z_{15} = shear stress,

x_7 = periphyton biomass.

	Description	Units
$g_{33} = x_7(b_{73} + b_{74}z_{15})$,	Large particle periphyton export	g m^{-2}

where

b_{73} = 0,

b_{74} = 7.4 x 10^{-3},

z_{15} = shear stress,

x_7 = periphyton biomass.

	Description	Units
$g_{34} = \max[0, x_7 - b_{72}]$,	Periphyton biomass available to grazers	g m^{-2}

where

b_{72} = 0.7,

x_7 = periphyton biomass.

	Description	Units
$g_{35} = b_{108}(1 + b_{37}z_1)$,	Decomposition (respiration) of CSLPOM and SLPOM per unit biomass	g g^{-1}

where

b_{37} = 0.294,

b_{108} = 9.11 x 10^{-4},

z_1 = water temperature.

	Description	Units
$g_{36} = b_{39} + b_{41} z_{15}$,	Export of CSLPOM and SLPOM per unit biomass	$g\ g^{-1}$

where

$b_{39} = 1.28 \times 10^{-4}$,

$b_{41} = 1.38 \times 10^{-3}$,

z_{15} = shear stress.

$g_{37} = b_{109}(1 + b_{38} z_1)$,	Decomposition (respiration) of CFLPOM and FLPOM per unit biomass	$g\ g^{-1}$

where

$b_{38} = 2.03$,

$b_{109} = 1.99 \times 10^{-4}$,

z_1 = water temperature.

$g_{38} = b_{40} + b_{42} z_{15}$,	Export of CFLPOM and FLPOM per unit biomass	$g\ g^{-1}$

where

$b_{40} = 1.28 \times 10^{-4}$,

$b_{42} = 1.38 \times 10^{-3}$,

z_{15} = shear stress.

$g_{39} = x_8 z_{14} \left[\dfrac{b_{110}}{1 + e^{(1.7 - b_{45} z_1)}} \right]$,	Decomposition (respiration) of FPOM	$g\ m^{-2}$

where

$b_{45} = 0.187$,

$b_{110} = 5.85 \times 10^{-2}$,

	Description	Units
z_{14} = current velocity effect,		
z_1 = water temperature,		
x_8 = FPOM biomass.		

$g_{40} = x_8(b_{46} + b_{47}z_{15})$, FPOM export $g\ m^{-2}$

where

$b_{46} = 2.33 \times 10^{-3}$,

$b_{47} = 1.74 \times 10^{-2}$,

z_{15} = shear stress,

x_8 = FPOM biomass.

$g_{41} = (x_9 + x_{11})g_{35} + (x_{10} + x_{12})g_{37}$, LPOM decomposition (respiration) $g\ m^{-2}$

where

g_{35} = decomposition of CSLPOM and SLPOM,

g_{37} = decomposition of CFLPOM and FLPOM,

x_9 = CSLPOM biomass,

x_{10} = CFLPOM biomass,

x_{11} = SLPOM biomass,

x_{12} = FLPOM biomass.

$g_{42} = (x_9 + x_{11})g_{36} + (x_{10} + x_{12})g_{38}$, LPOM export $g\ m^{-2}$

where

g_{36} = export of CSLPOM and SLPOM,

	Description	Units
g_{38} = export of CFLPOM and FLPOM,		
x_9 = CSLPOM biomass,		
x_{10} = CFLPOM biomass,		
x_{11} = SLPOM biomass,		
x_{12} = FLPOM biomass.		
$g_{43} = z_5 + z_6$,	LPOM input	g m^{-2}

where

z_5 = slow-conditioned allochthonous input,

z_6 = fast-conditioned allochthonous input.

$g_{44} = \min[x_{11}, \max(0, b_{31}(x_{11} - x_{13}))]$,	Transfer of SLPOM to CSLPOM	g m^{-2}

where

b_{31} = 9.95 x 10^{-2},

x_{11} = SLPOM biomass,

x_{13} = SLPOM conditioning gate.

$g_{45} = \min[x_{12}, \max(0, b_{32}(x_{12} - x_{14}))]$,	Transfer of FLPOM to CFLPOM	g m^{-2}

where

b_{32} = 0.465,

x_{12} = FLPOM biomass,

x_{14} = FLPOM conditioning gate.

	Description	Units
$g_{46} = \dfrac{b_{21}g_{34}}{1 + b_{21}g_{34}}$,	Food density limiting factor for grazers	none

where

b_{21} = 4,

g_{34} = periphyton biomass available to grazers.

$g_{47} = \min\left[1, \dfrac{1.2b_{28}(x_9 + x_{10})}{1 + b_{28}(x_9 + x_{10})}\right]$,	Food density limiting factor for shredders	none

where

b_{28} = 3.5,

x_9 = CSLPOM biomass,

x_{10} = CFLPOM biomass.

$g_{48} = g_{56} - g_{27}$,	Vertebrate predator capacity to reduce primary consumer biomass in the absence of competition with invertebrate predators	g m^{-2}

where

g_{27} = consumption of invertebrate predator biomass by vertebrate predators,

g_{56} = vertebrate predator capacity to reduce primary consumer and and invertebrate predator biomass.

g_{49} and g_{50}	Not used	

	Description	Units
$g_{51} = \min[g_2 g_{46}, g_{34}]$,	Consumption of periphyton biomass by grazers	g m^{-2}

where

g_2 = grazer demand for periphyton,

g_{34} = periphyton biomass available to grazers,

g_{46} = food density limiting factor for grazers.

$g_{52} = \min[g_6 g_{47}, x_9 + x_{10}]$,	Consumption of LPOM by shredders	g m^{-2}

where

g_6 = shredder demand for CSLPOM and CFLPOM,

g_{47} = food density limiting factor for shredders,

x_9 = CSLPOM biomass,

x_{10} = CFLPOM biomass.

$g_{53} = \min\left[g_{10}\left(\frac{b_{29}x_8}{1 + b_{29}x_8}\right), x_8\right]$,	Consumption of FPOM by collectors	g m^{-2}

where

b_{29} = 3.5,

g_{10} = collector demand for FPOM,

x_8 = FPOM biomass.

$g_{54} = \min[b_{23}(g_3 + g_7 + g_{11} + g_{24}), b_{25} g_{26}]$,	Consumption of drift by vertebrate predators	g m^{-2}

where

b_{23} = 1,

b_{25} = 0.5,

	Description	Units
g_3 = grazer emergence loss,		
g_7 = shredder emergence loss,		
g_{11} = collector emergence loss,		
g_{24} = invertebrate predator emergence loss,		
g_{26} = vertebrate predator demand for food.		

$$g_{55} = g_{23} \left\{ \begin{array}{ll} \dfrac{g_{21}}{10 b_{20}} & \text{if } g_{21} < b_{20}\,, \\ 0.9 - 0.8\left(\dfrac{b_{24} - g_{21}}{b_{24} - b_{20}}\right) & \text{if } b_{20} \le g_{21} < b_{24}\,, \\ \min\left[1,\ 0.9 + \dfrac{0.1(g_{21} - b_{24})}{b_{20}}\right] & \text{if } g_{21} \ge b_{24} \end{array} \right\}$$

	Description	Units
	Invertebrate predator capacity to reduce primary consumer biomass	$g\ m^{-2}$

where

b_{20} = 1.5,

b_{24} = 4,

g_{21} = primary consumer biomass available for consumption,

g_{23} = invertebrate predator demand for primary consumers.

$$g_{56} = (1 - b_{25}) g_{26} \left[\frac{b_{18}}{b_{18} + b_{19} e^{-b_{18}(g_{19} + g_{21})}} \right],$$

	Description	Units
	Vertebrate predator capacity to reduce primary consumer and invertebrate predator biomass	$g\ m^{-2}$

		Description	Units

where

b_{18} = 1.1,

b_{19} = 1.6×10^2,

b_{25} = 0.5,

g_{19} = invertebrate predator biomass available for consumption by vertebrate predators,

g_{21} = primary consumer biomass available for consumption by predators,

g_{26} = vertebrate predator demand for food.

$$g_{57} = \min\left[g_{55},\ b_{22}g_{21}\left(\frac{g_{55}}{g_{55} + g_{48}}\right)\right] ,$$

Consumption of primary consumers by invertebrate predators — g m^{-2}

where

b_{22} = 0.8,

g_{21} = primary consumer biomass available for consumption by predators,

g_{48} = vertebrate predator capacity to reduce primary consumer biomass,

g_{55} = invertebrate predator capacity to reduce primary consumer biomass.

$$g_{58} = \min\left[g_{48},\ (1 - b_{22})g_{21}\left(\frac{g_{48}}{g_{55} + g_{48}}\right)\right] ,$$

Consumption of primary consumers by vertebrate predators — g m^{-2}

	Description	Units

where

b_{22} = 0.8,

g_{21} = primary consumer biomass available for consumption by predators,

g_{48} = vertebrate predator capacity to reduce primary consumer biomass,

g_{55} = invertebrate predator capacity to reduce primary consumer biomass.

$$g_{59} = \left\{ \begin{array}{ll} 0 & \textit{if } x_7 < b_{64} \,, \\ x_7 b_{65} \left(\dfrac{x_7 - b_{64}}{b_{84} - b_{64}} \right) & \textit{if } b_{64} \le x_7 < b_{84} \,, \\ x_7 b_{65} & \textit{if } b_{84} \le x_7 \end{array} \right\} ,$$

Leakage of dissolved organic matter from periphyton biomass independent of photosynthesis — g m^{-2}

where

b_{64} = 3,

b_{65} = 0.01,

b_{84} = 15,

x_7 = the periphyton biomass.

$$g_{60} = b_{66}(e^{b_{67} g_{30}} - 1) + g_{59} \;,$$

Total export of dissolved organic matter (DOM) from periphyton — g m^{-2}

where

b_{66} = 2.8 x 10^{-2},

b_{67} = 0.583,

g_{30} = periphyton primary production,

g_{59} = leakage of DOM from periphyton.

4. F Functions (update increments): | Description | Units

	Description	Units
f_1	Not used	
$f_2 = b_{92}g_{51} - g_1 - g_3 - g_4$,	Grazer biomass update increment	g m^{-2}

where

b_{92} = 0.55 (assimilation efficiency),

g_1 = grazer respiration,

g_3 = grazer emergence losses,

g_4 = grazer losses to predators,

g_{51} = grazer consumption of periphyton.

	Description	Units
$f_3 = \left(\frac{b_{93}}{1 + b_{89}}\right) g_{52} - g_5 - g_7 - g_8$,	Shredder biomass update increment	g m^{-2}

where

b_{89} = 0.237,

b_{93} = 0.18,

g_5 = shredder respiration,

g_7 = shredder emergence losses,

g_8 = shredder losses to predation,

g_{52} = shredder consumption of LPOM.

	Description	Units
$f_4 = b_{94}g_{53} - g_9 - g_{11} - g_{12}$,	Collector biomass update increment	g m^{-2}

where

b_{94} = 0.21,

g_9 = collector respiration,

g_{11} = collector emergence losses,

g_{12} = collector losses to predation,

g_{53} = collector consumption of FPOM.

	Description	Units
$f_5 = b_{51}(g_{27} + g_{54} + g_{58}) - g_{25}$,	Vertebrate predator biomass uptdate increment	g m^{-2}

where

b_{51} = 0.86 (assimilation efficiency),

g_{25} = respiration and mortality losses for vertebrate predators,

g_{27} = vertebrate predator consumption of invertebrate predator biomass,

g_{54} = vertebrate predator consumption of drifting organisms,

g_{58} = vertebrate predator consumption of primary consumer biomass.

$f_6 = b_{58}g_{57} - g_{22} - g_{24} - g_{27}$,	Invertebrate predator biomass uptake increment	g m^{-2}

where

b_{58} = 0.82 (assimilation efficiency),

g_{22} = invertebrate predator respiration,

g_{24} = invertebrate predator emergence losses,

g_{27} = losses of invertebrate predator biomass to vertebrate predators,

g_{57} = invertebrate predator consumption of primary consumer biomass.

$f_7 = g_{30} - g_{29} - g_{32} - g_{33} - g_{51} - g_{60}$,	Periphyton biomass update increment	g m^{-2}

where

g_{29} = periphyton respiration,

g_{30} = periphyton primary production,

g_{32} = periphyton fine particle export,

g_{33} = periphyton large particle export, Description | Units

g_{51} = losses of periphyton to grazers,

g_{60} = periphyton leakage of dissolved organic matter.

$$f_8 = g_{20} + g_{28} - g_{39} - g_{40} - g_{53} \ ,$$

FPOM biomass update increment — $g\ m^{-2}$

where

g_{20} = FPOM generated by primary consumers,

g_{28} = FPOM generated by predators,

g_{39} = decomposition of FPOM,

g_{40} = FPOM export,

g_{53} = consumption of FPOM by collectors.

$$f_9 = \begin{Bmatrix} g_{44} & \text{if } x_9 \leq 0 \ , \\ g_{44} - g_{52}\left(\dfrac{x_9}{x_9 + x_{10}}\right) - x_9(g_{35} + g_{36}) & \text{otherwise} \end{Bmatrix} ,$$

CSLPOM biomass update increment — $g\ m^{-2}$

where

g_{35} = decomposition of CSLPOM,

g_{36} = export of CSLPOM,

g_{44} = transfer of SLPOM to CSLPOM,

g_{52} = consumption of LPOM by shredders,

x_9 = CSLPOM biomass,

x_{10} = CFLPOM biomass.

	Description	Units

$$f_{10} = \begin{Bmatrix} g_{45} & \text{if } x_{10} \le 0 \ , \\ g_{45} - g_{52}\left(\dfrac{x_{10}}{x_9 + x_{10}}\right) - x_{10}(g_{37} + g_{38}) & \text{otherwise} \end{Bmatrix} ,$$

CFLPOM biomass update increment

where

g_{37} = decomposition of CFLPOM,

g_{38} = export of CFLPOM,

g_{45} = transfer of FLPOM to CFLPOM,

g_{52} = consumption of LPOM by shredders,

x_9 = CSLPOM biomass,

x_{10} = CFLPOM biomass.

$$f_{11} = z_5 - g_{44} - x_{11}(g_{35} + g_{36}) \ ,$$

SLPOM biomass update increment — $g\ m^{-2}$

where

z_5 = slow-conditioned allochthonous input,

g_{35} = decomposition of SLPOM,

g_{36} = export of SLPOM,

g_{44} = transfer of SLPOM to CSLPOM,

x_{11} = SLPOM biomass.

$$f_{12} = z_6 - g_{45} - x_{12}(g_{37} + g_{38}) \ ,$$

FLPOM biomass update increment — $g\ m^{-2}$

where

z_6 = fast-conditioned allochthonous input,

g_{37} = decomposition of FLPOM,

	Description	Units
g_{38} = export of FLPOM,		
g_{45} = transfer of FLPOM to CFLPOM,		
x_{12} = FLPOM biomass.		

$$f_{13} = b_{33}x_{13}(1 - g_{35})(1 - g_{36}) + b_{35}z_5 - x_{13} \ ,$$ SLPOM to CSLPOM transfer gate — none

where

b_{33} = 0.895,

b_{35} = 1.9,

z_5 = slow-conditioned allochthonous input,

g_{35} = decomposition of CSLPOM and SLPOM,

g_{36} = export of CSLPOM and SLPOM,

x_{13} = SLPOM conditioning gate.

$$f_{14} = b_{34}x_{14}(1 - g_{37})(1 - g_{38}) + b_{36}z_6 - x_{14} \ ,$$ FLPOM to CFLPOM transfer gate — none

where

b_{34} = 0.56,

b_{36} = 1.51,

z_6 = fast-conditioned allochthonous input,

g_{37} = decomposition of FLPOM and CFLPOM,

g_{38} = export of FLPOM and CFLPOM,

x_{14} = FLPOM conditioning gate.

5. Y Functions (output variables):	Description	Units
$y_i = x_i$, for $i = 2, ..., 12$	See x list	g m^{-2}
$y_{13} = x_9 + x_{10}$	See x list	g m^{-2}
$y_{14} = x_{11} + x_{12}$	See x list	g m^{-2}

The following y functions can be used as plot variables for the analysis of mechanisms controlling state variable dynamics (see pages 26-40 in the tutorial). In calculating these variables, values of x_i are values used to calculate the f functions (i.e., state variables determined at time k - 1) -- not the current, updated state variable values determined for time k. The values of the k - 1 state variables are designated as memory variables m_i . For example, x_2 at time k - 1 is specified as m_2 .

$$y_1 = \frac{(b_{92}g_2 - g_1)}{m_2} ,$$

Potential to expand the grazer biomass — g g^{-1}

where

b_{92} = 0.55,

g_1 = grazer respiration,

g_2 = grazer demand for periphyton,

m_2 = grazer biomass at time k - 1.

$$y_{15} = \frac{(b_{92}g_{51} - g_1)}{m_2} ,$$

Grazer production per unit biomass — g g^{-1}

where

b_{92} = 0.55,

g_1 = grazer respiration,

g_{51} = grazer consumption of periphyton,

m_2 = grazer biomass at time k - 1.

	Description	Units
$$y_{16} = y_{15} - \frac{g_3}{m_2} ,$$	Grazer production minus emergence losses	g g^{-1}

where

y_{15} = grazer production per unit biomass,

g_3 = grazer emergence losses,

m_2 = grazer biomass at time k - 1.

$$y_{17} = y_{16} - \left(\frac{g_{57}}{g_{57} + g_{58}}\right)\left(\frac{g_4}{m_2}\right) ,$$	Grazer production minus loses to emergence and invertebrate predators	g g^{-1}

where

y_{16} = grazer production minus emergence losses,

g_4 = grazer losses to predators,

g_{57} = consumption of primary consumers by invertebrate predators,

g_{58} = consumption of primary consumers by vertebrate predators,

m_2 = grazer biomass at time k - 1.

$$y_{18} = y_{16} - \frac{g_4}{m_2} ,$$	Realized specific growth rate of the grazer biomass	g g^{-1}

where

g_4 = grazer losses to predators,

y_{16} = grazer production minus emergence losses,

	Description	Units
m_2 = grazer biomass at time k - 1.		

$$y_{19} = \frac{g_6\left(\frac{b_{93}}{1 + b_{89}}\right) - g_5}{m_3},$$

Potential to expand the shredder biomass — $g\ g^{-1}$

where

b_{89} = 0.237,

b_{93} = 0.18,

g_5 = shredder respiration,

g_6 = shredder demand for LPOM,

m_3 = shredder biomass at time k - 1.

$$y_{20} = \frac{g_{52}\left(\frac{b_{93}}{1 + b_{89}}\right) - g_5}{m_3},$$

Shredder production per unit biomass — $g\ g^{-1}$

where

b_{89} = 0.237,

b_{93} = 0.18,

g_5 = shredder respiration,

g_{52} = shredder consumption of LPOM,

m_3 = shredder biomass at time k - 1.

$$y_{21} = y_{20} - \frac{g_7}{m_3},$$

Shredder production minus emergence losses — $g\ g^{-1}$

where

g_7 = shredder emergence losses,

y_{20} = shredder production,

m_3 = shredder biomass at time k - 1.

	Description	Units
$$y_{22} = y_{21} - \frac{g_8\left(\frac{g_{57}}{g_{57} + g_{58}}\right)}{m_3} ,$$	Shredder production minus losses to emergence and invertebrate predators	g g^{-1}

where

g_8 = shredder losses to predators,

g_{57} = consumption of primary consumers by invertebrate predators,

g_{58} = consumption of primary consumers by vertebrate predators,

y_{21} = shredder production minus emergence losess,

m_3 = shredder biomass at time k - 1.

$$y_{23} = y_{21} - \frac{g_8}{m_3} ,$$	Realized specific growth rate of shredder biomass	g g^{-1}

where

g_8 = shredder losses to predation,

y_{21} = shredder production minus emergence losses,

m_3 = shredder biomass at time k - 1.

$$y_{24} = \frac{b_{94}g_{10} - g_9}{m_4} ,$$	Potential to expand collector biomass	g g^{-1}

where

b_{94} = 0.21,

g_9 = collector respiration,

g_{10} = collector demand for FPOM,

m_4 = collector biomass at time k - 1.

	Description	Units
$$y_{25} = \frac{b_{94} g_{53} - g_9}{m_4} ,$$	Collector production per unit biomass	g g^{-1}

where

b_{94} = 0.21,

g_9 = collector respiration,

g_{53} = collector consumption of FPOM,

m_4 = collector biomass at time k - 1.

$$y_{26} = y_{25} - \frac{g_{11}}{m_4} ,$$	Collector production minus emergence losses	g g^{-1}

where

g_{11} = collector emergence losses,

y_{25} = collector production,

m_4 = collector biomass at time k - 1.

$$y_{27} = y_{26} - \frac{g_{12}\left(\frac{g_{57}}{g_{57} + g_{58}}\right)}{m_4} ,$$	Collector production minus losses to emergence and invertebrate predation	g g^{-1}

where

g_{12} = collector losses to predators,

g_{57} = consumption of primary consumers by invertebrate predators,

g_{58} = consumption of primary consumers by vertebrate predators,

y_{26} = collector production minus emergence losses,

m_4 = collector biomass at time k - 1.

	Description	Units
$y_{28} = y_{26} - \frac{g_{12}}{m_4}$,	Realized specific growth of the collector biomass	g g^{-1}

where

g_{12} = collector losses to predation,

y_{26} = collector production minus emergence losses,

m_4 = collector biomass at time k - 1.

$y_{29} = \frac{b_{58}g_{23} - g_{22}}{m_6}$,	Potential to expand the invertebrate predator biomass	g g^{-1}

where

b_{58} = 0.82,

g_{22} = invertebrate predator respiration,

g_{23} = invertebrate predator demand for primary consumers,

m_6 = invertebrate predator biomass at time k - 1.

$y_{30} = \frac{b_{58}g_{57} - g_{22}}{m_6}$,	Invertebrate predator production per unit biomass	g g^{-1}

where

b_{58} = 0.82,

g_{22} = invertebrate predator respiration,

g_{57} = invertebrate predator consumption of primary consumers,

m_6 = invertebrate predator biomass at time k - 1.

	Description	Units
$y_{31} = y_{30} - \dfrac{g_{24}}{m_6}$,	Invertebrate predator production minus emergence losses	g g^{-1}

where

g_{24} = invertebrate predator emergence losses,

y_{30} = invertebrate predator production,

m_6 = invertebrate predator biomass at time k - 1.

$y_{32} = y_{31} - \dfrac{g_{27}}{m_6}$,	Realized specific growth rate of invertebrate predator biomass	g g^{-1}

where

g_{27} = losses of invertebrate predator biomass to vertebrate predators,

y_{31} = invertebrate predator production minus emergence losses,

m_6 = invertebrate predator biomass at time k - 1.

$y_{33} = \dfrac{b_{51}g_{26} - g_{25}}{m_5}$,	Potential to expand the vertebrate predator biomass	g g^{-1}

where

b_{51} = 0.86,

g_{25} = vertebrate predator natural mortality and respiration,

g_{26} = vertebrate predator demand for food,

m_5 = vertebrate predator biomass at time k - 1.

	Description	Units
$$y_{34} = \frac{b_{51}[(1 - b_{25})g_{26} + g_{54}] - g_{25}}{m_5},$$ where b_{25} = 0.5, b_{51} = 0.86, g_{25} = vertebrate predator natural mortality and respiration, g_{26} = vertebrate predator demand for food, g_{54} = vertebrate predator consumption of drifting organisms, m_5 = vertebrate predator biomass at time k - 1.	Potential to expand the the vertebrate predator biomass when a fraction of the demand (b_{25}) must be satisfied by drift feeding or left unsatisfied	$g\ g^{-1}$
$$y_{35} = \frac{b_{51}(g_{48} + g_{54} + g_{27}) - g_{25}}{m_5},$$ where b_{51} = 0.86, g_{25} = vertebrate predator natural mortality and respiration, g_{27} = vertebrate predator consumption of invertebrate predator biomass, g_{54} = vertebrate predator consumption of drifting organisms, g_{48} = vertebrate predator consumption of primary consumers in the absence of competition with invertebrate predators, m_5 = vertebrate predator biomass at time k - 1.	vertebrate predator production per unit biomass (minus natural mortality) in the absence of competition with invertebrate predators	$g\ g^{-1}$

	Description	Units
$$y_{36} = \frac{b_{51}(g_{58} + g_{54} + g_{27}) - g_{25}}{m_5} ,$$	Realized specific growth rate of vertebrate predator biomass	$g\ g^{-1}$

where

b_{51} = 0.86,

g_{25} = vertebrate predator respiration and natural mortality,

g_{27} = vertebrate predator consumption of invertebrate predator biomass,

g_{54} = vertebrate predator consumption of drifting organisms,

g_{58} = vertebrate predator consumption of primary consumers,

m_5 = vertebrate predator biomass at time k - 1.

$$y_{37} = \frac{\left(\frac{g_{30}}{g_{14}g_{15}}\right) - g_{29}}{m_7} ,$$	Net periphyton production per unit biomass at optimum light and nutrient supply (unlimited resources)	$g\ g^{-1}$

where

g_{14} = nutrient limiting coefficient,

g_{15} = light limiting coefficient,

g_{29} = periphyton respiration,

g_{30} = periphyton primary produciton,

m_7 = periphyton biomass at time k - 1.

$$y_{38} = \frac{g_{30} - g_{29}}{m_7} ,$$	Realized net periphyton production per unit biomass	$g\ g^{-1}$

where

g_{29} = periphyton respiration,

	Description	Units

g_{30} = periphyton primary production,

m_7 = periphyton biomass at time k - 1.

$$y_{39} = y_{38} - \frac{g_{32} + g_{33}}{m_7} ,$$

Realized net periphyton production minus particulate export (> 0.45 μm) — g g^{-1}

where

g_{32} = fine particle export,

g_{33} = large particle export,

y_{38} = realized net periphyton production,

m_7 = periphyton biomass at time k - 1.

$$y_{40} = y_{39} - \frac{g_{60}}{m_7} ,$$

Realized net periphyton production minus total export (including dissolved organic matter) — g g^{-1}

where

y_{39} = realized net periphyton production minus particulate export,

g_{60} = export of dissolved organic matter from periphyton,

m_7 = periphyton biomass at time k - 1.

$$y_{41} = y_{40} - \frac{g_{51}}{m_7} ,$$

Realized specific growth rate of periphyton biomass — g g^{-1}

where

y_{40} = realized net periphyton production minus export,

g_{51} = consumption of periphyton by grazers,

m_7 = periphyton biomass at time k - 1.

6. B Parameters:

List	Value	Description	In Function
b_1		Not used*	
b_2	1.39×10^{-2}	Channel slope	z_{13}, z_{15}
b_3	5.7×10^{-2}	Current effect parameter	z_{14}
b_4	12	Mean annual temperature	z_1
b_5	6	One-half the temperature range	z_1
b_6	0.114	Channel depth parameter	z_{10}
b_7	0.581	Channel depth parameter	z_{10}
b_8	1.97×10^{-4}	Suspended load parameter	z_7
b_9	-94.4	Suspended load parameter	z_7
b_{10}	9.42×10^{3}	Suspended load parameter	z_7
b_{11}	1.08×10^{3}	Suspended load parameter	z_7
b_{12}	4.88×10^{-2}	Roughness parameter	z_8
b_{13}	8.83×10^{-2}	Roughness parameter	z_8
b_{14}	10.2	Channel width parameter	z_{11}
b_{15}	2.95×10^{-3}	Channel width parameter	z_{11}
b_{16}	1.07	Cross sectional area parameter	z_9
b_{17}	0.633	Cross sectional area parameter	z_9
b_{18}	1.1	Food density limiting rate parameter for vertebrate predators	g_{56}
b_{19}	1.6×10^{2}	Food density limiting rate parameter for vertebrate predators	g_{56}
b_{20}	1.5	Food density limiting rate parameter for invertebrate predators	g_{55}
b_{21}	4	Food density limiting rate parameter for grazers	g_{46}
b_{22}	0.8	Competition coefficient	g_{57}, g_{58}
b_{23}	1	Emergence index parameter for drift feeding	g_{54}

List	Value	Description	In Function
b_{24}	4	Food density limiting rate parameter for invertebrate predators	g_{55}
b_{25}	0.5	Fraction of vertebrate predator demand to be met by drift	g_{54}, g_{56}
b_{26}		Not used*	
b_{27}		Not used*	
b_{28}	3.5	Food density limiting rate parameter for shredders	g_{47}
b_{29}	3.5	Food density limiting rate parameter for collectors	g_{53}
b_{30}		Not used	
b_{31}	9.95×10^{-2}	SLPOM conditioning parameter	g_{44}
b_{32}	0.465	FLPOM conditioning parameter	g_{45}
b_{33}	0.895	SLPOM conditioning rate parameter	f_{13}
b_{34}	0.56	FLPOM conditioning rate parameter	f_{14}
b_{35}	1.9	SLPOM conditioning rate parameter	f_{13}
b_{36}	1.51	FLPOM conditioning rate parameter	f_{14}
b_{37}	0.294	Decomposition rate parameter for CSLPOM and SLPOM	g_{35}
b_{38}	2.03	Decomposition rate parameter for CFLPOM and FLPOM	g_{37}
b_{39}	1.28×10^{-4}	Export rate parameter for CSLPOM and SLPOM	g_{36}
b_{40}	1.28×10^{-4}	Export rate parameter for CFLPOM and FLPOM	g_{38}
b_{41}	1.38×10^{-3}	Export rate parameter for CSLPOM and SLPOM	g_{36}
b_{42}	1.38×10^{-3}	Export rate parameter for CFLPOM and FLPOM	g_{38}
b_{43}	12	Mean annual photoperiod	z_{17}
b_{44}	4	Photoperiod fluctuation parameter	z_{17}

List	Value	Description	In Function
b_{45}	0.187	Decomposition rate parameter for FPOM	g_{39}
b_{46}	2.33×10^{-3}	Export rate parameter for FPOM	g_{40}
b_{47}	1.74×10^{-2}	Export rate parameter for FPOM	g_{40}
b_{48}		Not used*	
b_{49}		Not used*	
b_{50}	0.3	Refuge parameter for invertebrate predators	g_{19}
b_{51}	0.86	Assimilation ratio for vertebrate predators	g_{28}, f_5, y_{33} y_{34}, y_{35}, y_{36}
b_{52}	0.1	Cost of consumption for vertebrate predators	g_{25}
b_{53}	1.87×10^{-3}	Vertebrate predator respiration rate parameter	g_{25}
b_{54}	2.5×10^{-3}	Specific mortality rate for vertebrate predators	g_{25}
b_{55}	2.6×10^{-2}	Vertebrate predator demand parameter	g_{26}
b_{56}	1.88×10^{-2}	Invertebrate predator respiration rate parameter	g_{22}
b_{57}	0.42	Invertebrate predator emergence scaling parameter	g_{24}
b_{58}	0.82	Invertebrate predator assimilation ratio	$g_{28}, f_6, y_{29}, y_{30}$
b_{59}	0.05	Invertebrate predator demand parameter	g_{23}
b_{60}	100	Invertebrate predator demand-temperature parameter	g_{23}
b_{61}		Not used*	
b_{62}		Not used*	
b_{63}		Not used*	
b_{64}	3	Periphyton dissolved organic matter export parameter	g_{59}
b_{65}	0.01	Periphyton dissolved organic matter export parameter	g_{59}

List	Value	Description	In Function
b_{66}	2.8×10^{-2}	Periphyton dissolved organic matter export parameter	g_{60}
b_{67}	0.583	Periphyton dissolved organic matter export parameter	g_{60}
b_{68}	1×10^{-3}	Nutrient limiting parameter for primary production	g_{14}
b_{69}	0.5	Nutrient limiting parameter for primary production	g_{14}
b_{70}	1.92×10^{-2}	Periphyton fine particle export parameter	g_{32}
b_{71}	2.1×10^{-3}	Primary production light limiting parameter	g_{15}
b_{72}	0.7	Periphyton refuge from grazing	g_{34}
b_{73}	0	Periphyton large particle export parameter	g_{33}
b_{74}	7.4×10^{-3}	Periphyton large particle export parameter	g_{33}
b_{75}	1.08×10^{-3}	Periphyton fine particle export parameter	g_{32}
b_{76}	0.1	Primary production biomass limiting parameter	g_{31}
b_{77}	0.4	Primary production temperature limiting parameter	g_{31}
b_{78}	2.68×10^{2}	Primary production nutrient limiting parameter	g_{14}
b_{79}	2.95	Maximum possible rate of primary production expressed as O_2 m^{-2} hr^{-1}	g_{30}
b_{80}	0.187	Periphyton respiration-temperature parameter	g_{29}
b_{81}	1.46×10^{-2}	Grazer respiration parameter	g_{1}
b_{82}	2.96×10^{-2}	Shredder respiration parameter	g_{5}
b_{83}	1.46×10^{-2}	Collector respiration parameter	g_{9}
b_{84}	15	Periphyton dissolved organic matter export parameter	g_{59}
b_{85}	0.8	Grazer emergence scaling parameter	g_{3}

List	Value	Description	In Function
b_{86}	12	Shredder emergence scaling parameter	g_7
b_{87}	0.35	Collector emergence scaling parameter	g_{11}
b_{88}	0.7	Shredder demand parameter	g_6
b_{89}	0.237	Fraction of shredder demand transferred mechanically to FPOM	g_6, g_{20}, f_3, y_{19}, y_{20}
b_{90}	1×10^3	Primary production light limiting parameter	g_{15}
b_{91}	2.4×10^3	Light saturation intensity for primary production in ft-c	g_{15}
b_{92}	0.55	Grazer assimilation ratio	g_{20},f_2, y_1, y_{15}
b_{93}	0.18	Shredder assimilation ratio	g_{20}, f_3, g_{19}, y_{20}
b_{94}	0.21	Collector assimilation ratio	g_{20}, f_4, y_{24}, y_{25}
b_{95}		Not used*	
b_{96}	0.3	Grazer refuge parameter	g_4, g_{21}
b_{97}	0.3	Shredder refuge parameter	g_8, g_{21}
b_{98}	0.3	Collector refuge parameter	g_{12}, g_{21}
b_{99}	0.167	Shredder demand-temperature parameter	g_6
b_{100}	1	Grazer demand parameter	g_2
b_{101}	4.46×10^{-3}	Grazer respiration parameter	g_1
b_{102}	4.46×10^{-3}	Shredder respiration parameter	g_5
b_{103}	4.46×10^{-3}	Collector respiration parameter	g_9
b_{104}	-1	Constant allochthonous input (fast conditioned material)	z_6
b_{105}	1.44×10^{-4}	Vertebrate predator respiration parameter	g_{25}
b_{106}	0	Invertebrate predator respiration parameter	g_{22}
b_{107}	5.85×10^{-2}	Periphyton respiration parameter	g_{29}
b_{108}	9.11×10^{-4}	Decomposition parameter for CSLPOM and SLPOM	g_{35}
b_{109}	1.99×10^{-4}	Decomposition parameter for CFLPOM and FLPOM	g_{37}

List	Value	Description	In Function
b_{110}	5.85×10^{-2}	Decomposition parameter for FPOM	g_{39}
b_{111}	-1	Constant nutrient input	z_3
b_{112}	-1	Constant stream flow	z_4
b_{113}	-1	Constant light input	z_2
b_{114}	-1	Constant allochthonous input (slow conditioned material)	z_5

* *During the development of* **Version I** *of the M & C Stream Model, functions and parameters were added and deleted as model structure evolved toward the version presented in this documentation. Consequently, some parameters (and a state variable and a few g functions) are missing from the sequence of numbers that span the range of values used in the present model structure. Therefore, the user should not attach any significance to the unused symbols indicated in this documentation.*

7. Initial Conditions

These initial values for the state variables correspond to parameter values and input tables for the Standard Run of Version I of the M & C Stream Model. When these values are introduced in the command file (i.e., in STREAM.CMD on page 17) along with the parameters listed above in Section 6 and the input tables in Appendix II, the model will exhibit steady state behavior and generate the output listed in Appendix III and Appendix IX.

X List	Value
x_1	Not used
x_2	1.816
x_3	1.4
x_4	2.177
x_5	3.509
x_6	0.26
x_7	0.924
x_8	10.4
x_9	122
x_{10}	24
x_{11}	31
x_{12}	1
x_{13}	17
x_{14}	0.66

APPENDIX II

INPUT TABLES FOR THE STANDARD RUN OF THE M & C STREAM MODEL: VERSION I

These input tables correspond to the Standard Run of Version I of the M & C Stream Model. Each table consists of 360 values representing a period of one year based on twelve 30-day months at a time resolution of 1 day. Read each row in the tables from left to right for the correct chronological order.

Note: *In the original program for Version I of the model, tables representing the emergence schedules for grazers (GEMER), shredders (SEMER), collectors (CEMER), and invertebrate predators (PEMER) were a series of emergence losses, each value representing a 15-day period of time. Therefore, each table had 24 values, and the program interpolated these values for each day during the 15-day periods. In the current program for Version I, the 15-day totals are interpolated and the each table now contains 360 values. Because these interpolations were based on the 15-day totals, the program divides each value by 15 to adjust the inputs to a daily value. If the user decides to use these tables in another model, the values in each table must be divided by 15 to make the necessary adjustment to a value representing a daily loss.*

1. <u>Table</u>: EXLITE

   <u>Unit</u>: ft-c

   <u>Description</u>: Daily mean illumination intensity for one year (360 days)

   <u>Values</u>:

1031	1037	1042	1047	1052	1057	1062	1068	1073	1078	1083	1089
1094	1099	1104	1110	1115	1120	1125	1130	1136	1141	1146	1151
1157	1162	1167	1172	1178	1183	1188	1217	1246	1275	1304	1333
1362	1391	1420	1449	1478	1507	1536	1565	1594	1623	1652	1680
1709	1738	1767	1796	1825	1854	1883	1912	1941	1970	1999	2028
2057	2038	2019	2000	1981	1962	1943	1924	1905	1886	1867	1848
1829	1810	1791	1772	1753	1733	1715	1695	1676	1657	1638	1619
1600	1581	1562	1543	1524	1505	1486	1444	1402	1360	1318	1276
1234	1192	1150	1107	1065	1023	981	939	897	855	813	771
729	687	645	603	561	518	476	434	392	350	308	266
224	222	221	219	217	215	213	212	210	208	206	205
203	201	199	198	196	194	192	190	189	187	185	183
182	180	178	176	175	173	171	170	170	169	169	168
167	167	166	165	165	164	163	163	162	162	161	160
160	159	158	158	157	156	156	155	155	154	153	153
152	150	148	147	145	143	141	139	138	136	134	132

130	129	127	125	123	121	120	118	116	114	112	111
109	107	105	103	102	100	98	101	103	106	109	112
114	117	120	122	125	128	130	133	136	139	141	144
147	149	152	155	157	160	163	166	168	171	174	176
179	177	175	173	171	169	166	164	162	160	158	156
154	152	150	148	145	143	141	139	137	135	133	131
129	127	124	122	120	118	116	132	149	165	182	198
215	231	248	264	281	297	314	330	347	363	380	396
412	429	445	462	478	495	511	528	544	561	577	594
610	624	638	652	666	680	694	708	722	736	750	764
778	792	807	821	835	849	863	877	891	905	919	933
947	961	975	989	1003	946	889	894	899	903	908	913
917	922	927	932	936	941	946	951	955	960	965	969
974	979	984	988	993	998	1003	1007	1012	1017	1022	1026

2. Table: XNUTR

Unit: mg l^{-1}

Description: Daily nitrate concentration for one year (360 days)

Values:

.014	.014	.014	.013	.013	.013	.012	.012	.012	.011	.011	.011
.010	.010	.010	.009	.009	.009	.008	.008	.008	.007	.007	.007
.006	.006	.006	.005	.005	.005	.004	.004	.004	.004	.004	.004
.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
.004	.004	.004	.004	.004	.004	.004	.004	.004	.003	.003	.003
.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003
.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002
.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002
.002	.002	.002	.002	.002	.002	.003	.003	.003	.003	.003	.003
.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003
.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003
.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
.004	.004	.004	.003	.003	.003	.003	.003	.003	.003	.003	.003
.003	.003	.003	.003	.003	.003	.002	.002	.002	.003	.003	.003
.004	.004	.004	.005	.005	.005	.006	.006	.006	.007	.007	.007
.008	.008	.008	.009	.009	.009	.010	.010	.010	.010	.010	.010
.011	.011	.012	.013	.014	.015	.016	.016	.017	.018	.019	.020
.021	.021	.022	.023	.024	.025	.026	.026	.027	.028	.029	.030
.031	.031	.032	.033	.034	.034	.035	.034	.033	.032	.031	.030
.029	.028	.027	.026	.025	.024	.023	.022	.021	.020	.019	.018
.016	.015	.014	.012	.011	.010	.009	.008	.007	.006	.005	.004

.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003
.003	.003	.003	.003	.003	.004	.004	.004	.004	.004	.004	.004
.004	.004	.004	.004	.004	.004	.005	.005	.005	.006	.006	.006
.007	.007	.007	.008	.008	.008	.009	.009	.009	.010	.010	.010
.011	.011	.011	.011	.012	.012	.012	.012	.013	.013	.013	.013

3. <u>Table</u>: STRFLOW

<u>Unit</u>: cfs

<u>Description</u>: Stream flow input for one year (360 days)

<u>Values</u>:

11.20	6.20	6.02	5.84	5.66	5.48
5.30	5.30	11.80	14.00	13.45	10.20
9.20	6.80	125.50	113.33	98.00	71.33
51.17	31.00	26.50	25.50	26.00	44.50
63.00	29.00	19.00	14.50	15.54	16.58
17.63	18.67	19.71	20.75	12.50	11.98
11.45	10.93	10.40	9.76	9.12	8.48
7.84	7.20	8.30	7.35	6.40	7.80
7.60	7.40	7.20	7.00	8.38	9.77
11.15	10.00	9.00	8.43	7.85	7.28
6.70	8.20	21.67	15.50	12.60	12.40
25.05	37.70	50.35	63.00	88.54	52.00
31.50	25.00	17.50	14.25	11.00	10.76
10.52	10.29	10.05	9.81	9.57	9.34
9.10	8.86	8.62	8.38	8.15	7.91
7.67	7.43	7.19	6.96	6.72	6.48
6.24	6.00	5.77	5.53	5.29	5.05
4.81	4.58	4.34	4.10	3.86	3.63
3.39	3.15	2.91	2.67	2.44	2.20
1.96	1.72	1.48	1.25	1.01	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77

.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77
.77	.77	.77	.72	.68	.68
.68	.67	.68	.68	.67	.67
.69	.68	.71	.72	.80	.76
.82	.76	2.37	1.20	.89	1.18
1.55	1.12	.94	1.50	1.75	1.30
1.30	1.55	1.45	1.86	1.38	1.93
1.40	1.20	3.10	2.10	3.10	5.35
4.40	4.10	18.04	7.90	3.90	2.64
2.16	1.90	1.70	1.58	1.45	2.41
3.38	4.34	5.30	83.33	14.60	13.34
12.09	10.83	9.57	8.31	7.06	5.80
10.33	14.85	19.38	23.90	28.43	32.95
37.48	42.00	37.37	32.74	28.11	23.49
18.86	14.23	9.60	9.80	10.00	10.20
10.40	10.60	10.80	11.00	11.20	9.53
7.87	6.20	.77	.77	.77	.77
.77	.77	.77	.77	.77	.77

4. Table: SALLOC

Unit: g m^{-2} day^{-1}

Description: Slow-conditioned allochthonous input for one year (360 days)

Values:

.806	.799	.792	.784	.777	.770	.764	.758	.752	.746
.740	.735	.730	.725	.720	.715	.711	.707	.704	.700
.696	.694	.692	.689	.687	.685	.683	.681	.679	.677
.675	.674	.673	.672	.670	.669	.671	.674	.676	.679
.681	.684	.687	.690	.693	.696	.699	.702	.705	.708
.711	.714	.717	.720	.723	.726	.729	.732	.735	.738
.741	.744	.747	.750	.752	.755	.751	.747	.743	.740
.736	.730	.723	.717	.711	.705	.700	.695	.690	.685
.679	.677	.676	.674	.672	.670	.668	.666	.664	.662
.660	.660	.660	.660	.660	.660	.661	.662	.663	.664
.665	.664	.664	.663	.663	.662	.657	.652	.647	.642
.637	.632	.627	.621	.616	.610	.605	.601	.596	.591
.586	.585	.583	.581	.579	.578	.576	.575	.573	.572
.571	.570	.570	.570	.570	.569	.587	.605	.623	.640

.658	.682	.706	.730	.754	.778	.806	.834	.862	.890
.918	.946	.974	1.002	1.030	1.058	1.069	1.080	1.092	1.103
1.115	1.126	1.137	1.146	1.157	1.167	1.178	1.188	1.198	1.209
1.219	1.229	1.239	1.249	1.258	1.268	1.265	1.261	1.257	1.254
1.250	1.235	1.219	1.203	1.187	1.172	1.155	1.138	1.121	1.104
1.087	1.070	1.053	1.036	1.019	1.002	.986	.969	.952	.935
.918	.900	.883	.865	.848	.830	.810	.790	.771	.751
.731	.712	.693	.674	.655	.636	.633	.631	.629	.627
.624	.627	.631	.634	.637	.640	.644	.647	.650	.653
.657	.666	.676	.686	.695	.705	.756	.807	.859	.910
.961	1.019	1.077	1.135	1.192	1.250	1.308	1.365	1.422	1.480
1.537	1.593	1.649	1.705	1.761	1.817	1.847	1.876	1.906	1.935
1.964	1.954	1.944	1.934	1.924	1.913	1.903	1.893	1.883	1.873
1.863	1.853	1.842	1.832	1.822	1.812	1.802	1.791	1.781	1.771
1.761	1.757	1.753	1.748	1.744	1.739	1.772	1.805	1.838	1.870
1.903	1.942	1.981	2.020	2.058	2.097	2.136	2.175	2.213	2.252
2.291	2.329	2.368	2.407	2.445	2.484	2.523	2.562	2.600	2.639
2.678	2.695	2.711	2.728	2.745	2.762	2.710	2.659	2.608	2.556
2.505	2.441	2.377	2.313	2.249	2.185	2.121	2.057	1.992	1.928
1.864	1.800	1.736	1.672	1.607	1.543	1.479	1.415	1.351	1.287
1.223	1.178	1.133	1.088	1.043	.998	.976	.953	.931	.908
.886	.878	.871	.863	.856	.848	.840	.831	.823	.814

5. Table: FALLOC

Unit: g m^{-2} day^{-1}

Description: Fast-conditioned allochthonous input for one year (360 days)

Values:

.167	.165	.164	.162	.160	.158	.157	.155	.153	.152
.150	.149	.147	.145	.144	.142	.142	.141	.141	.140
.139	.140	.141	.142	.143	.144	.144	.145	.146	.147
.148	.149	.150	.150	.151	.152	.153	.154	.156	.157
.158	.158	.159	.160	.161	.162	.161	.161	.160	.160
.160	.159	.159	.158	.158	.157	.157	.156	.156	.155
.155	.154	.153	.153	.152	.152	.151	.149	.148	.147
.146	.145	.143	.142	.140	.139	.138	.137	.136	.135
.135	.135	.136	.136	.137	.138	.138	.139	.139	.140
.141	.142	.143	.144	.145	.146	.147	.148	.149	.150
.151	.152	.152	.153	.153	.154	.153	.152	.151	.150
.149	.147	.146	.145	.144	.143	.141	.140	.139	.138
.137	.136	.135	.134	.133	.132	.131	.130	.129	.128
.128	.127	.126	.125	.125	.124	.127	.129	.132	.135
.138	.142	.145	.149	.153	.157	.160	.163	.166	.168
.171	.174	.176	.179	.181	.184	.183	.182	.181	.181
.180	.179	.178	.177	.176	.175	.174	.173	.172	.171
.170	.169	.168	.167	.166	.165	.164	.162	.161	.160

.159	.156	.154	.151	.149	.146	.144	.141	.138	.136
.133	.130	.128	.125	.122	.120	.117	.114	.111	.109
.106	.103	.101	.098	.095	.093	.090	.088	.085	.082
.080	.077	.075	.073	.070	.068	.069	.071	.073	.074
.076	.079	.082	.085	.088	.091	.094	.097	.100	.103
.106	.109	.112	.115	.118	.121	.124	.128	.131	.135
.138	.142	.145	.149	.152	.156	.159	.161	.164	.167
.169	.170	.170	.170	.171	.171	.172	.173	.173	.174
.175	.177	.179	.181	.183	.185	.187	.189	.191	.193
.195	.197	.199	.201	.203	.205	.206	.208	.210	.212
.214	.218	.221	.225	.228	.232	.246	.259	.273	.287
.300	.316	.331	.346	.361	.377	.392	.407	.422	.438
.453	.468	.483	.499	.514	.529	.544	.560	.575	.590
.606	.616	.627	.638	.649	.660	.649	.638	.627	.616
.605	.589	.573	.557	.540	.524	.508	.492	.475	.459
.443	.427	.411	.394	.378	.362	.346	.329	.313	.297
.281	.271	.260	.250	.240	.230	.228	.226	.223	.221
.218	.221	.224	.227	.230	.233	.220	.207	.194	.181

6. Table: GEMER

Units: g m^{-2} day^{-1} times 15 (divide each value by 15 to get the daily loss)

Description: Daily grazer emergence losses times 15 for one year

Values:

.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.001	.003	.004	.005	.007	.008	.009	.011	.012	.013	.015	.016
.017	.019											
.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020
.020	.020											
.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020
.020	.020											
.020	.025	.031	.036	.041	.047	.052	.057	.063	.068	.073	.079	.084
.089	.095											
.100	.113	.127	.140	.153	.167	.180	.193	.207	.220	.233	.247	.260
.273	.287											
.300	.287	.273	.260	.247	.233	.220	.207	.193	.180	.167	.153	.140
.127	.113											
.100	.097	.095	.092	.089	.087	.084	.081	.079	.076	.073	.071	.068
.065	.063											
.060	.058	.056	.054	.052	.050	.048	.046	.044	.042	.040	.038	.036
.034	.032											

.030	.029	.029	.028	.027	.027	.026	.025	.025	.024	.023	.023	.022
.021	.021											
.020	.020	.019	.019	.019	.018	.018	.018	.017	.017	.017	.016	.016
.016	.015											
.015	.015	.014	.014	.014	.013	.013	.013	.012	.012	.012	.011	.011
.011	.010											
.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
.010	.010											
.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
.010	.010											
.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
.010	.010											
.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
.010	.010											
.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
.010	.010											
.010	.009	.009	.008	.007	.007	.006	.005	.005	.004	.003	.003	.002
.001	.001											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											

7. Table: SEMER

Units: g m^{-2} day^{-1} times 15 (divide each value by 15 to get the daily loss)

Description: Daily shredder emergence losses times 15 for one year

Values:

.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0											
.0	.0	.001	.001	.002	.002	.002	.003	.003	.004	.004	.004	.005
.005	.006											
.006	.007	.009	.010	.012	.013	.015	.016	.018	.019	.020	.022	.023
.025	.026											
.028	.026	.025	.024	.022	.021	.019	.018	.017	.015	.014	.013	.011
.010	.008											
.007	.007	.006	.006	.006	.006	.005	.005	.005	.004	.004	.004	.004

```
.003 .003
.003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003
.003 .003
.003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003 .003
.003 .003
.004 .004 .004 .004 .004 .004 .004 .004 .004 .004 .004 .004 .004
.004 .004
.004 .004 .004 .004 .004 .004 .004 .004 .004 .004 .004 .004 .004
.004 .004
.004 .004 .004 .005 .005 .005 .005 .005 .006 .006 .006 .006 .006
.007 .007
.007 .007 .007 .007 .007 .008 .008 .008 .008 .008 .008 .008 .008
.009 .009
.009 .009 .009 .009 .009 .009 .009 .009 .009 .010 .010 .010 .010
.010 .010
.010 .010 .011 .011 .011 .012 .012 .012 .013 .013 .013 .014 .014
.014 .015
.015 .017 .019 .020 .022 .024 .025 .028 .029 .031 .033 .035 .037
.038 .040
.042 .041 .040 .040 .039 .038 .037 .036 .036 .035 .034 .033 .032
.032 .031
.030 .029 .029 .028 .027 .027 .026 .025 .025 .024 .023 .023 .022
.021 .021
.020 .019 .019 .018 .017 .017 .016 .015 .015 .014 .013 .013 .012
.011 .011
.010 .009 .009 .008 .007 .007 .006 .005 .005 .004 .003 .003 .002
.001 .001
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
```

8. Table: CEMER

Units: g m^{-2} day^{-1} times 15 (divide each value by 15 to get the daily loss)

Description: Daily collector emergence losses times 15 for one year

Values:

```
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
```

```
.0   .0
.0   .007 .013 .020 .027 .033 .040 .047 .053 .060 .067 .073 .080
.087 .093
.100 .107 .113 .120 .127 .133 .140 .147 .153 .160 .167 .173 .180
.187 .193
.200 .227 .253 .280 .307 .333 .360 .387 .413 .440 .467 .493 .520
.547 .573
.600 .627 .653 .680 .707 .733 .760 .787 .813 .840 .867 .893 .920
.947 .973
1.000 .947 .893 .840 .787 .733 .680 .627 .573 .520 .467 .413 .360
.307 .253
.200 .193 .187 .180 .173 .167 .160 .153 .147 .140 .133 .127 .120
.113 .107
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .117 .133 .150 .167 .183 .200 .217 .233 .250 .267 .283 .300
.317 .333
.350 .367 .383 .400 .417 .433 .450 .467 .483 .500 .517 .533 .550
.567 .583
.600 .567 .533 .500 .467 .433 .400 .367 .333 .300 .267 .233 .200
.167 .133
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100 .100
.100 .100
.100 .093 .087 .080 .073 .067 .060 .053 .047 .040 .033 .027 .020
.013 .007
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
.0   .0
```

9. <u>Table</u>: PEMER

<u>Unit</u>: g m^{-2} day^{-1} times 15 (divide each value by 15 to get the daily loss)

<u>Description</u>: Daily invertebrate predator emergence losses times 15 for one year

<u>Values</u>:

.010 .011 .012 .012 .013 .014 .015 .016 .016 .017 .018 .019 .020
.021 .022
.022 .024 .025 .027 .028 .030 .032 .033 .035 .036 .038 .040 .041
.043 .044
.046 .048 .049 .051 .053 .055 .056 .058 .060 .062 .063 .065 .067
.069 .070
.072 .075 .077 .080 .082 .085 .088 .090 .093 .095 .096 .101 .103
.106 .108
.111 .111 .112 .112 .112 .113 .113 .113 .114 .114 .114 .115 .115
.115 .116
.116 .117 .118 .119 .119 .120 .121 .122 .123 .124 .125 .126 .126
.127 .128
.129 .126 .124 .121 .118 .116 .113 .110 .108 .105 .102 .100 .097
.094 .092
.089 .086 .083 .080 .078 .075 .072 .069 .066 .063 .060 .057 .055
.052 .049
.046 .046 .046 .045 .045 .045 .045 .045 .044 .044 .044 .044 .044
.043 .043
.043 .042 .042 .041 .040 .040 .039 .038 .038 .037 .036 .036 .035
.034 .034
.033 .033 .032 .032 .031 .031 .031 .030 .030 .029 .029 .029 .028
.028 .027
.027 .026 .026 .025 .025 .024 .023 .023 .022 .022 .021 .020 .020
.019 .019
.018 .018 .019 .019 .020 .020 .021 .021 .022 .022 .023 .023 .024
.024 .025
.025 .026 .027 .027 .028 .029 .030 .031 .031 .032 .033 .034 .035
.035 .036
.037 .038 .039 .039 .040 .041 .042 .043 .043 .044 .045 .046 .047
.047 .048
.049 .053 .057 .060 .064 .068 .072 .076 .079 .083 .087 .091 .094
.098 .102
.106 .110 .114 .119 .123 .127 .131 .135 .140 .144 .148 .152 .156
.161 .165
.169 .177 .185 .193 .202 .210 .218 .226 .234 .242 .250 .258 .267
.275 .283
.291 .283 .275 .266 .258 .250 .242 .234 .225 .217 .209 .201 .193
.184 .176
.168 .160 .152 .144 .136 .128 .120 .112 .104 .096 .088 .080 .072
.064 .056
.048 .047 .047 .046 .045 .045 .044 .043 .043 .042 .041 .041 .040
.039 .039
.038 .037 .037 .036 .035 .035 .034 .033 .033 .032 .031 .031 .030

.029 .029
.028 .027 .027 .026 .025 .024 .024 .023 .022 .021 .021 .020 .019
.018 .018
.017 .017 .016 .016 .015 .015 .014 .014 .013 .013 .012 .012 .011
.011 .010

10. Table: STRTEMP

Units: °C

Description: Daily mean stream temperature for one year (360 days)

Values:

6.000 6.001 6.004 6.008 6.015 6.023 6.033 6.045 6.058
6.074 6.091 6.110
6.131 6.154 6.178 6.204 6.232 6.262 6.294 6.327 6.362
6.398 6.437 6.477
6.519 6.562 6.607 6.654 6.702 6.752 6.804 6.857 6.911
6.968 7.025 7.085
7.145 7.208 7.271 7.337 7.403 7.471 7.541 7.611 7.683
7.757 7.831 7.907
7.984 8.063 8.143 8.223 8.305 8.388 8.472 8.558 8.644
8.731 8.819 8.909
8.999 9.090 9.182 9.275 9.369 9.463 9.558 9.654 9.751
9.848 9.947 10.045
10.145 10.244 10.345 10.446 10.547 10.649 10.751 10.854 10.957
11.060 11.163 11.267
11.371 11.475 11.580 11.684 11.789 11.894 11.998 12.103 12.208
12.312 12.417 12.521
12.625 12.729 12.833 12.937 13.040 13.143 13.245 13.348 13.450
13.551 13.652 13.752
13.852 13.951 14.050 14.148 14.246 14.342 14.438 14.534 14.628
14.722 14.815 14.907
14.998 15.088 15.177 15.266 15.353 15.439 15.525 15.609 15.692
15.774 15.855 15.934
16.013 16.090 16.166 16.241 16.314 16.386 16.457 16.526 16.594
16.661 16.726 16.790
16.852 16.913 16.973 17.030 17.087 17.141 17.195 17.246 17.296
17.345 17.391 17.437
17.480 17.522 17.562 17.600 17.637 17.672 17.705 17.737 17.767
17.795 17.821 17.845
17.868 17.889 17.908 17.926 17.941 17.955 17.967 17.977 17.985
17.992 17.996 17.999
18.000 17.999 17.996 17.992 17.986 17.977 17.968 17.956 17.942
17.927 17.910 17.890
17.870 17.847 17.823 17.797 17.769 17.739 17.708 17.674 17.640
17.603 17.565 17.525
17.483 17.440 17.395 17.348 17.300 17.250 17.198 17.145 17.091

17.034 16.977 16.917
16.857 16.794 16.731 16.666 16.599 16.531 16.462 16.391 16.319
16.246 16.171 16.095
16.018 15.940 15.860 15.779 15.698 15.615 15.530 15.445 15.359
15.272 15.184 15.094
15.004 14.913 14.821 14.728 14.635 14.540 14.445 14.349 14.252
14.155 14.057 13.958
13.859 13.759 13.659 13.558 13.456 13.355 13.252 13.150 13.047
12.944 12.840 12.736
12.632 12.528 12.424 12.319 12.215 12.110 12.005 11.901 11.796
11.691 11.587 11.482
11.378 11.274 11.170 11.067 10.964 10.861 10.758 10.656 10.554
10.453 10.352 10.251
10.151 10.052 9.953 9.855 9.758 9.661 9.565 9.470 9.375
9.281 9.188 9.096
9.005 8.915 8.826 8.737 8.650 8.563 8.478 8.394 8.311
8.229 8.148 8.068
7.990 7.913 7.837 7.762 7.688 7.616 7.545 7.476 7.408
7.341 7.276 7.212
7.150 7.089 7.029 6.972 6.915 6.860 6.807 6.755 6.705
6.657 6.610 6.565
6.521 6.480 6.439 6.401 6.364 6.329 6.296 6.264 6.234
6.206 6.180 6.155
6.133 6.112 6.092 6.075 6.059 6.046 6.034 6.023 6.015
6.009 6.004 6.001

11. Table: PHOTPER

Units: hr day^{-1}

Description: Number of daylight hours per day for one year (360 days)

Values:

8.000 8.001 8.002 8.005 8.010 8.015 8.022 8.030 8.039
8.049 8.061 8.073
8.087 8.102 8.119 8.136 8.155 8.175 8.196 8.218 8.241
8.266 8.291 8.318
8.346 8.375 8.405 8.436 8.468 8.501 8.536 8.571 8.608
8.645 8.684 8.723
8.764 8.805 8.848 8.891 8.935 8.981 9.027 9.074 9.122
9.171 9.221 9.272
9.323 9.375 9.428 9.482 9.537 9.592 9.648 9.705 9.763
9.821 9.880 9.939
9.999 10.060 10.121 10.183 10.246 10.309 10.372 10.436 10.501
10.566 10.631 10.697
10.763 10.830 10.896 10.964 11.031 11.099 11.167 11.236 11.304
11.373 11.442 11.511
11.581 11.650 11.720 11.789 11.859 11.929 11.999 12.069 12.138

12.208 12.278 12.347
12.417 12.486 12.555 12.624 12.693 12.762 12.830 12.898 12.966
13.034 13.101 13.168
13.235 13.301 13.367 13.432 13.497 13.562 13.626 13.689 13.752
13.815 13.877 13.938
13.999 14.059 14.118 14.177 14.235 14.293 14.350 14.406 14.461
14.516 14.570 14.623
14.675 14.727 14.777 14.827 14.876 14.924 14.971 15.018 15.063
15.107 15.151 15.193
15.235 15.276 15.315 15.354 15.391 15.428 15.463 15.498 15.531
15.563 15.594 15.624
15.653 15.681 15.708 15.734 15.758 15.781 15.804 15.825 15.844
15.863 15.881 15.897
15.912 15.926 15.939 15.950 15.961 15.970 15.978 15.985 15.990
15.994 15.997 15.999
16.000 15.999 15.998 15.995 15.990 15.985 15.978 15.970 15.961
15.951 15.940 15.927
15.913 15.898 15.882 15.864 15.846 15.826 15.805 15.783 15.760
15.735 15.710 15.683
15.655 15.626 15.596 15.565 15.533 15.500 15.465 15.430 15.394
15.356 15.318 15.278
15.238 15.196 15.154 15.110 15.066 15.021 14.975 14.927 14.879
14.831 14.781 14.730
14.679 14.627 14.573 14.520 14.465 14.410 14.354 14.297 14.239
14.181 14.122 14.063
14.003 13.942 13.881 13.819 13.756 13.693 13.630 13.566 13.501
13.437 13.371 13.305
13.239 13.173 13.106 13.039 12.971 12.903 12.835 12.767 12.698
12.629 12.560 12.491
12.422 12.352 12.283 12.213 12.143 12.073 12.004 11.934 11.864
11.794 11.725 11.655
11.586 11.516 11.447 11.378 11.309 11.240 11.172 11.104 11.036
10.968 10.901 10.834
10.768 10.701 10.636 10.570 10.505 10.441 10.377 10.313 10.250
10.188 10.126 10.064
10.003 9.943 9.884 9.825 9.767 9.709 9.652 9.596 9.541
9.486 9.432 9.379
9.327 9.275 9.224 9.175 9.126 9.077 9.030 8.984 8.939
8.894 8.851 8.808
8.766 8.726 8.686 8.648 8.610 8.574 8.538 8.504 8.470
8.438 8.407 8.377
8.348 8.320 8.293 8.267 8.243 8.219 8.197 8.176 8.156
8.137 8.120 8.104
8.088 8.074 8.062 8.050 8.040 8.030 8.022 8.016 8.010
8.006 8.003 8.001

APPENDIX III

OUTPUT OF STATE VARIABLE VALUES FOR THE STANDARD RUN OF THE M & C STREAM MODEL: VERSION I

Appendix III represents the output generated by the simulation run described on pages 11 and 12 of this tutorial. In this case, state variables x_2 (grazer biomass), x_3 (shredder biomass), x_4 (collector biomass), x_5 (vertebrate predator biomass), x_6 (invertebrate predator biomass), x_7 (periphyton biomass), and x_9 (CSLPOM biomass) were requested at a time resolution of 30 days (see **pset** and **pint** commands on page 14). The output also includes a list of all parameter values, initial values for state and memory variables, and a list of input tables.

```
Flex5-PC : A Model Processor

 Run No.: 1

 Target Level: 1
 Target title: Stream Model


 Initial Conditions

 B - Parameters   (114)
      0.000  1.390E-002  5.700E-002      -1.000       0.000       0.114
      0.581  1.970E-004     -94.400    9420.000    1080.000  4.880E-002
 8.830E-002      10.200  2.950E-003       1.070       0.633       1.100
    160.000       1.500       4.000       0.800       1.000       4.000
      0.500       0.000       0.000       3.500       3.500       0.000
 9.950E-002       0.465       0.895       0.560       1.900       1.510
      0.294       2.030  1.280E-004  1.280E-004  1.380E-003  1.380E-003
     -1.000       0.000       0.187  2.330E-003  1.740E-002       0.000
      0.000       0.300       0.860       0.100  1.870E-003  2.500E-003
 2.600E-002  1.880E-002       0.420       0.820  5.000E-002     100.000
      0.000       0.000       0.000       3.000  1.000E-002  2.800E-002
      0.583  1.000E-003       0.500  1.920E-002  2.100E-003       0.700
      0.000  7.400E-003  1.080E-003       0.100       0.400     268.000
      2.950       0.187  1.460E-002  2.960E-002  1.460E-002      15.000
      0.800      12.000       0.350       0.700       0.237    1000.000
   2400.000       0.550       0.180       0.210       0.000       0.300
      0.300       0.300       0.167       1.000  4.460E-003  4.460E-003
 4.460E-003      -1.000  1.440E-004       0.000  5.850E-002  9.110E-004
 1.990E-004  5.850E-002      -1.000      -1.000      -1.000      -1.000

 X - State Variables   (14)
      0.000       1.415       1.305       3.075       3.974       0.112
```

```
     0.932        8.228       123.962      24.700       30.851       1.145
    16.978        0.668

M - Memory   (7)
     0.000        0.000        0.000        0.000        0.000        0.000
     0.000

Table (1): EXLITE
Table (2): XNUTR
Table (3): STRFLOW
Table (4): SALLOC
Table (5): FALLOC
Table (6): GEMER
Table (7): SEMER
Table (8): CEMER
Table (9): PEMER
Table (10): STRTEMP
Table (11): PHOTPER


Print Interval: 30
Variable Headings
    x[2]         x[3]         x[4]         x[5]         x[6]         x[7]
    x[9]

k = 0
     1.415        1.305        3.075        3.974        0.112        0.932
   123.962

k = 30
     0.937        1.911        4.293        4.263        0.210        0.957
   108.343

k = 60
     3.091        2.741        5.552        4.964        0.379        1.015
    77.168

k = 90
     2.214        2.514        5.331        7.311        0.610        1.032
    38.255

k = 120
     1.147        2.140        2.592       10.088        0.851        0.805
     8.412

k = 150
     0.471        0.852        1.754        9.552        0.834        0.827
     0.546

k = 180
     0.426        0.683        1.502        8.113        0.573        0.822
     5.366
```

k = 210					
0.290	0.590	1.384	6.846	0.359	0.786
19.382					
k = 240					
0.449	0.453	1.326	5.942	0.216	0.917
27.301					
k = 270					
0.447	0.331	1.178	5.410	0.115	0.802
35.794					
k = 300					
1.420	0.459	1.464	4.720	6.698E-002	1.173
65.677					
k = 330					
1.353	0.813	2.085	4.199	7.250E-002	0.775
96.225					
k = 360					
1.415	1.305	3.075	3.974	0.112	0.932
123.967					

APPENDIX IV

ANNUAL ENERGY BUDGET TABLES GENERATED FROM THE STANDARD RUN FOR VERSION I OF THE M & C STREAM MODEL

The following tables represent output from BUDGET.COM after STREAM.DMP was introduced as input. In this case, STREAM.DMP was the dump file from the Standard Run of Version I of the M & C Stream Model (See page 23). The output listed in Appendix IV is stored in the file STREAM.TAB.

```
*****************************************************************************************************
*                                                                                                   *
*                              MCINTIRE AND COLBY STREAM MODEL                                      *
*                                                                                                   *
*                              Energy Budget - Annual Resolution                                    *
*                                                                                                   *
*                              Simulation Run No. Standard Run                                      *
*                                                                                                   *
*****************************************************************************************************
```

Table 1. Bioenergetics of the Major Biological Processes

Property	GRAZE	SRED	COLLECT	V-PRED	I-PRED	ALGAE
Biomass (g/m2):						
Mean	1.077	1.237	2.627	6.283	0.367	0.938
Std Dev	0.709	0.829	1.519	2.009	0.276	0.222
Maximum	3.091	2.847	5.881	10.241	0.923	1.904
Minimum	0.254	0.330	1.162	3.970	0.066	0.548
Production (g/m2/yr):						
Gross Primary						70.912
Net Periphyton						60.892
Secondary	3.366	6.313	12.204	5.643	0.736	
Assimilation (g/m2/yr)	26.955	41.654	71.730	15.999	3.220	
Turnover (times/yr)	3.124	5.104	4.646	0.898	2.002	64.896
Energy Losses (g/m2/yr):						
Respiration/post-mortum decomposition	23.590	35.341	59.527	10.355	2.485	10.020
To invert. predation	0.670	1.099	2.159			
To vert. predation	2.044	2.847	5.899		0.503	
To grazing						49.009
Emergence	0.661	2.385	4.185		0.235	
Vert. mortality				5.645		
Periphyton export:						
Large particle						2.853
Fine particle						7.767
DOM leakage						1.254
Energy Losses (% of assimilation):						
Respiration/post-mortum decompostion	87.51%	84.85%	82.99%	64.73%	77.16%	14.13%
To invert. predation	2.49%	2.64%	3.01%			
To vert. predation	7.58%	6.84%	8.22%		15.62%	
To grazing						69.11%
Emergence	2.45%	5.72%	5.83%		7.29%	
Vert. mortality				35.28%		
Periphyton export:						
Large particle						4.02%
Fine particle						10.95%
DOM leakage						1.77%

Table 2. Bioenergetics of Detrital Processes

Property	FPOM	Total LPOM	Conditioned SLPOM	Conditioned FLPOM	Unconditioned SLPOM	Unconditioned FLPOM
Biomass (g/m2):						
Mean	10.338	89.428	50.422	9.566	28.847	1.096
Std Dev	5.793	56.110	40.756	8.426	14.046	0.691
Maximum	24.257	184.119	124.788	24.700	63.912	3.509
Minimum	4.063	0.000	0.477	0.119	15.312	0.389
Inputs (g/m2/yr):						
Terrestrial SLPOM		401.057				
Terrestrial FLPOM		71.829				
Aquatic (feces):						
Primary consumption	481.653					
Predation	3.311					
Mechanical from LPOM	54.844					
Energy Losses (g/m2/yr):						
Microbial decomposition	118.341	113.031				
To collecting	341.574					
To shredding		231.409				
Export	80.154	73.348				
Mechanical to FPOM		54.844				
Energy Losses (% of total inputs):						
Microbial decomposition	21.92%	23.90%				
To collecting	63.28%					
To shredding		48.94%				
Export	14.85%	15.51%				
Mechanical to FPOM		11.60%				

Table 3. Ecosystem Energy Budget (g/m2/yr)

Property	Inputs	Outputs
Gross Primary Production (GPP)	70.912	
Allochthonous Materials:		
SLPOM	401.057	
FLPOM	71.829	
Drift from Upstream	7.309	
Community Respiration (CR)		372.689
Insect Emergence		7.465
Export/Natural Mortality		171.022
Total	551.107	551.176
Net Gain or Loss	-0.068	
GPP/CR	0.190	

APPENDIX V

MATHEMATICAL DOCUMENTATION FOR THE M & C STREAM MODEL: HERBIVORY VERSION

Introduction

Much of the mathematical documentation for the Herbivory Version of the M & C Stream Model is the same as the documentation presented for Version I of the model (Appendix I). In this section, the only functions written out in full are those that are new to the Herbivory Version or have a different mathematical form than their representation in Version I. When a function for the Herbivory Version is identical to that presented for Version I, the user is referred to the corresponding page number where the equation can be found in Appendix I.

In the Herbivory Version of the model, the set of rules that assigns the new increment of primary production to the biomasses of the three functional groups of algae is implemented by a set of conditional statements in the Pascal code. In the case of the variables $\mathbf{g_{2}}$, $\mathbf{g_{61}}$, $\mathbf{g_{62}}$, and $\mathbf{g_{63}}$, the conditional statements are complex and more difficult to document using the convention established in Appendix I. Consequently, in this section, the mathematical form of these functions is represented as a series of IF, THEN, and ELSE statements similar in structure to the Pascal code.

Mathematical Documentation

TITLE:	McIntire and Colby Stream Model: Herbivory Version
INVESTIGATOR:	C. David McIntire
DATE:	1986-1994
TIME RESOLUTION:	1 day (360 days = 1 year)
QUANTITY MODELED:	Biomass expressed as organic matter (dry weight)

VARIABLES AND FUNCTIONS:

1\. X List

X List	Description	Units
x_1	Not used	-
x_2	Grazer biomass	g m^{-2}
x_3	Shredder biomass	g m^{-2}
x_4	Collector biomass	g m^{-2}
x_5	Vertebrate predator biomass	g m^{-2}
x_6	Invertebrate predator biomass	g m^{-2}
x_7	Periphyton biomass	g m^{-2}
x_8	Fine particulate organic matter biomass (FPOM)	g m^{-2}
x_9	Conditioned allochthonous biomass - slow rate (CSLPOM)	g m^{-2}
x_{10}	Conditioned allochthonous biomass - fast rate (CFLPOM)	g m^{-2}
x_{11}	Unconditioned allochthonous biomass - slow rate (SLPOM)	g m^{-2}
x_{12}	Unconditioned allochthonous biomass - fast rate (FLPOM)	g m^{-2}
x_{13}	SLPOM conditioning gate	none
x_{14}	FLPOM conditioning gate	none
x_{15}	Diatom biomass	g m^{-2}
x_{16}	Cyanobacteria biomass	g m^{-2}
x_{17}	Chlorophyte biomass	g m^{-2}

2\. Z Functions (input functions):

Z Functions	Description	Units
z_1	Appendix I: page 150	
z_2	Appendix I: page 150	
z_3	Appendix I: page 150	

	Description	Units
z_4	Appendix I: page 150	
z_5	Appendix I: page 150	
z_6	Appendix I: page 150	
z_7	Appendix I: page 150	
z_8	Appendix I: page 151	
z_9	Appendix I: page 151	
z_{10}	Appendix I: page 151	
z_{11}	Appendix I: page 151	
z_{12}	Appendix I: page 151	
z_{13}	Appendix I: page 152	
z_{14}	Appendix I: page 152	
z_{15}	Appendix I: page 152	

$$z_{16} = b_{120} z_2 \exp[-z_{10} 0.305 \min(3,\ \max(0.03,\ 0.03 z_7 + 0.2))] \quad ,$$

	Description	Units
z_{16}	Effective illumination intensity at stream bottom	ft-c

where

z_2 = illumination intensity,

z_{10} = stream depth,

z_7 = suspended load,

b_{120} = irradiation multiplier.

	Description	Units
z_{17}	Appendix I: page 153	

3. <u>G Functions</u> (intermediate functions): **Description** **Units**

	Description	Units
g_1	Appendix I: page 153	

$$
g_2 = \begin{cases} b_{100}x_2g_{64}b_{115}z_1 & \text{if } z_1 < 2.0, \\ b_{100}x_2g_{64}[(b_{116}z_1) + b_{117}] & \text{if } 2.0 \le z_1 \le 18.0, \\ b_{100}\, x_2g_{64}[(b_{118}z_1) + b_{119}] & \text{if } 18.0 < z_1 < 30.0, \\ 0 \quad \text{if } z_1 \ge 30.0 & \end{cases} ,
$$

	Description	Units
g_2	Grazer demand for periphyton	$g\ m^{-2}$

where

b_{100} = 1.0,

b_{115} = 0.03,

b_{116} = 0.0175,

b_{117} = 0.025,

b_{118} = -0.0283,

b_{119} = 0.849,

x_2 = grazer biomass,

z_1 = water temperature,

g_{64} = food quality limiting factor.

	Description
g_3	Appendix I, page 154
g_4	Appendix I, page 154
g_5	Appendix I, page 154
g_6	Appendix I, page 154
g_7	Appendix I, page 155
g_8	Appendix I, page 155

	Description	Units
g_9	Appendix I, page 155	
g_{10}	Appendix I, page 156	
g_{11}	Appendix I, page 156	
g_{12}	Appendix I, page 156	
g_{13}	Appendix I, page 156	
g_{14}	Appendix I, page 157	
g_{15}	Appendix I, page 157	
g_{16} *through* g_{18}	Not used	
g_{19}	Appendix I, page 158	

$$g_{20} = (1 - g_{65})g_{51} + \left(1 - \frac{b_{93}}{1 + b_{89}}\right)g_{52} + (1 - b_{94})g_{53} \,,$$

	Description	Units
	FPOM generated by primary consumption	g m^{-2}

where

b_{89} = 0.237, the fraction of consumption by shredders that represents mechanical transfer,

g_{65} = 0.55, assimilation ratio for grazers,

b_{93} = 0.18, assimilation ratio for shredders,

b_{94} = 0.21, assimilation ratio for collectors,

g_{51} = consumption of periphyton by grazers,

g_{52} = consumption of CSLPOM and CFLPOM by shredders,

g_{53} = consumption of FPOM by collectors.

	Description	Units
g_{21}	Appendix I, page 159	
g_{22}	Appendix I, page 159	
g_{23}	Appendix I, page 159	
g_{24}	Appendix I, page 160	
g_{25}	Appendix I, page 160	
g_{26}	Appendix I, page160	
g_{27}	Appendix I, page 161	
g_{28}	Appendix I, page 161	
g_{29}	Appendix I, page 162	
g_{30}	Appendix I, page 162	
g_{31}	Appendix I, page 162	
g_{32}	Appendix I, page 163	
g_{33}	Appendix I, page 163	
g_{34}	Appendix I, page 163	
g_{35}	Appendix I, page 163	
g_{36}	Appendix I, page 164	
g_{37}	Appendix I, page 164	
g_{38}	Appendix I, page 164	
g_{39}	Appendix I, page 164	
g_{40}	Appendix I, page 165	

	Description	Units
g_{41}	Appendix I, page 165	
g_{42}	Appendix I, page 165	
g_{43}	Appendix I, page 166	
g_{44}	Appendix I, page 166	
g_{45}	Appendix I, page 166	
g_{46}	Appendix I, page 167	
g_{47}	Appendix I, page 167	
g_{48}	Appendix I, page 167	
g_{49} and g_{50}	Not used	
g_{51}	Appendix I, page 168	
g_{52}	Appendix I, page 168	
g_{53}	Appendix I, page 168	
g_{54}	Appendix I, page 168	
g_{55}	Appendix I, page 169	
g_{56}	Appendix I, page 169	

$$g_{57} = \left\{ \begin{array}{ll} \min\left[g_{55},\ b_{22}g_{21}\left(\frac{g_{55}}{g_{55} + g_{48}}\right)\right] & \textit{if } g_{55} + g_{48} > 0 \\ 0 \quad \textit{otherwise} & \end{array} \right\},$$

	Description	Units
	Consumption of primary consumers by vertebrate predators	g m^{-2}

	Description	Units

where

b_{22} = 0.8,

g_{21} = primary consumer biomass available for consumption by predators,

g_{48} = vertebrate predator capacity to reduce primary consumer biomass,

g_{55} = invertebrate predator capacity to reduce primary consumer biomass.

$$g_{58} = \begin{Bmatrix} \min\left[g_{48},\ (1 - b_{22})g_{21}\left(\dfrac{g_{48}}{g_{55} + g_{48}}\right)\right] & \text{if } g_{55} + g_{48} > 0 \\ 0 \quad \textit{otherwise} & \end{Bmatrix},$$

Consumption of primary consumers by vertebrate predators — $g\ m^{-2}$

where

b_{22} = 0.8,

g_{21} = primary consumer biomass available for consumption by predators,

g_{48} = vertebrate predator capacity to reduce primary consumer biomass,

g_{55} = invertebrate predator capacity to reduce primary consumer biomass.

g_{59} — Appendix I, page 171

$$g_{60} = \begin{Bmatrix} 0.17\, g_{30} + g_{59} & \text{if } g_{30} > 6.0 \\ b_{66}[e^{b_{67} g_{30}} - 1] + g_{59} & \textit{otherwise} \end{Bmatrix},$$

Total export of dissolved organic matter (DOM) from periphyton — $g\ m^{-2}$

where

b_{66} = 2.8 x 10^{-2},

b_{67} = 0.583,

	Description	Units

g_{30} = periphyton primary production,

g_{59} = leakage of DOM from periphyton.

Note: g_{61} and g_{62} are written as a series of IF, THEN, *and* ELSE *statements that must executed in order*

	Description	Units
IF x_7 < *2.0* THEN g_{61} = *1.00* ELSE IF x_7 <= *45.0* THEN g_{61} = *-0.01209* * $(x_7 - 2.0)$ + *1.0* ELSE g_{61} = *0.48* IF x_7 < *30* THEN g_{62} = *0.0* ELSE IF x_7 <= *45.0* THEN g_{62} = *0.003* * $(x_7 - 30.0)$ ELSE g_{62} = *0.04*	g_{61} and g_{62} are the proportions of the primary production update increment that are diatoms and cyanobacteria, respectively	none

IF z_{16} * *0.2* < *300.0* THEN

IF z_{16} * *0.2* >= *30.0* THEN

IF x_7 < *2.0* THEN g_{61} = *1.00*
ELSE IF x_7 <= *25.0* THEN
g_{61} = *-0.02261* * $(x_7 - 2.0)$ + *1.00*
ELSE g_{61} = *0.48*

IF x_7 < *2.0* THEN g_{62} = *0.0*
ELSE IF x_7 <= *5.0* THEN
g_{62} = *0.06333* * $(x_7 - 2.0)$
ELSE g_{62} = *0.19*

IF z_{16} * *0.2* <= *150.0* THEN
$g_{61} = ((0.004333 * (150.0 - (z_{16} * 0.2)))/0.52) * (1.0 - g_{61}) + g_{61}$

IF z_{16} * *0.2* <= *50.0* THEN
$g_{62} = -((0.0095 * (50.0 - (z_{16} * 0.2)))/0.19) * (g_{62}) + g_{62}$
ELSE IF g_{62} >= *0.04* THEN
$g_{62} = ((0.0006 * (50.0 - (z_{16} * 0.2)))/0.15) * (g_{62} - 0.04) + g_{62}$

	Description	Units
$g_{70} = g_{61} g_{30}$,	Diatom primary production	g m^{-2}

where
g_{30} = periphyton primary production,
g_{61} = proportion of diatoms.

$g_{71} = g_{62} g_{30}$,	Cyanobacteria primary production	g m^{-2}

where
g_{30} = periphyton primary production,
g_{62} = proportion of cyanobacteria.

$g_{72} = g_{63} g_{30}$,	Chlorophyte primary production	g m^{-2}
$g_{73} = \dfrac{b_{121} - 0.48}{-0.52}$,	Food quality scaling function 1	none

where
b_{121} = food quality limiting factor minimum value.

$g_{74} = 1.0 + g_{73}$,	Food quality scaling function 2	none

where
g_{73} = food quality scaling function 1.

4. F Functions (update increments):	Description	Units
f_1	Not used	
$f_2 = g_{65} g_{51} - g_1 - g_3 - g_4$,	Grazer biomass update increment	g m^{-2}

	Description	Units

where

g_{65} = grazer assimilation ratio,

g_1 = grazer respiration,

g_3 = grazer emergence losses,

g_4 = grazer losses to predators,

g_{51} = grazer consumption of periphyton.

f_3	Appendix I, page 172	
f_4	Appendix I, page 172	
f_5	Appendix I, page 173	
f_6	Appendix I, page 173	
f_7	Appendix I, page 173	
f_8	Appendix I, page 174	

$$f_9 = \left\{ \begin{array}{ll} -x_9 & \text{if } x_9 + f_9 < 0 \, , \\ g_{44} & \text{if } x_9 + f_9 \geq 0 \text{ and if } x_9 \leq 0 \, , \\ g_{44} - g_{52}\left(\dfrac{x_9}{x_9 + x_{10}}\right) - x_9(g_{35} + g_{36}) & \text{otherwise} \end{array} \right\} ,$$

	Description	Units
	CSLPOM biomass update increment	g m^{-2}

where

g_{35} = decomposition of CSLPOM,

g_{36} = export of CSLPOM,

g_{44} = transfer of SLPOM to CSLPOM,

g_{52} = consumption of LPOM by shredders,

x_9 = CSLPOM biomass,

x_{10} = CFLPOM biomass.

	Description	Units

$$f_{10} = \begin{Bmatrix} -x_{10} & \text{if } x_{10} + f_{10} < 0 , \\ g_{45} & \text{if } x_{10} + f_{10} \geq 0 \text{ and if } x_{10} \leq 0 , \\ g_{45} - g_{52}\left(\dfrac{x_{10}}{x_9 + x_{10}}\right) - x_{10}(g_{37} + g_{38}) & \text{otherwise} \end{Bmatrix} ,$$

CFLPOM biomass update increment — $g\ m^{-2}$

where

g_{37} = decomposition of CFLPOM,

g_{38} = export of CFLPOM,

g_{45} = transfer of FLPOM to CFLPOM,

g_{52} = shredder consumption of LPOM

x_9 = CSLPOM biomass,

x_{10} = CFLPOM biomass.

f_{11} — Appendix I, page 175

f_{12} — Appendix I, page 175

f_{13} — Appendix I, page 176

f_{14} — Appendix I, page 176

$$f_{15} = \begin{Bmatrix} -x_{15} & \text{if } x_{15} + f_{15} < 0 \\ g_{70} - g_{67} & \text{otherwise} \end{Bmatrix} ,$$

Diatom biomass update increment — $g\ m^{-2}$

where

x_{15} = diatom biomass,

g_{67} = total diatom energy losses,

g_{70} = diatom primary production.

$$f_{16} = \begin{Bmatrix} -x_{16} & \text{if } x_{16} + f_{16} < 0 \\ g_{71} - g_{68} & \text{otherwise} \end{Bmatrix} ,$$

Cyanobacteria biomass update increment — $g\ m^{-2}$

Description	Units

where

x_{16} = cyanobacteria biomass,

g_{68} = total cyanobacteria energy losses,

g_{71} = cyanobacteria primary production.

$$f_{17} = \begin{Bmatrix} -x_{17} & \textit{if } x_{17} + f_{17} < 0 \\ g_{72} - g_{69} & \textit{otherwise} \end{Bmatrix},$$

Chlorophyte biomass update increment — g m^{-2}

where

x_{17} = chlorophyte biomass,

g_{69} = total chlorophyte energy losses,

g_{72} = chlorophyte primary production.

5. Y Functions (output variables):

	Description	Units
$y_i = x_i$, for $i = 2, \dots\dots\dots, 12$	See x list	g m^{-2}
$y_{13} = x_9 + x_{10}$	See x list	g m^{-2}
$y_{14} = x_{11} + x_{12}$	See x list	g m^{-2}
y_1	Appendix I, page 177	
y_{15}	Appendix I, page 177	
y_{16}	Appendix I, page 178	

$$y_{17} = \begin{Bmatrix} 0 & \textit{if } g_{57} + g_{58} \le 0 \\ y_{16} - \left(\dfrac{g_{57}}{g_{57} + g_{58}}\right)\left(\dfrac{g_4}{m_2}\right) & \textit{otherwise} \end{Bmatrix},$$

Grazer production minus loses to emergence and invertebrate predators — g g^{-1}

where

y_{16} = grazer production minus emergence losses,

g_4 = grazer losses to predators,

		Description	Units
	g_{57} = consumption of primary consumers by invertebrate predators,		
	g_{58} = consumption of primary consumers by vertebrate predators,		
	m_2 = grazer biomass at time k - 1.		
y_{18}		Appendix I, page 178	
y_{19}		Appendix I, page 179	
y_{20}		Appendix I, page 179	
y_{21}		Appendix I, page 179	

$$y_{22} = \left\{ \begin{array}{ll} 0 & if\ g_{57} + g_{58} \le 0 \\ y_{21} - \dfrac{g_8\left(\dfrac{g_{57}}{g_{57} + g_{58}}\right)}{m_3} & otherwise \end{array} \right\},$$

Shredder production minus losses to emergence and invertebrate predators — $g\ g^{-1}$

where

g_8 = shredder losses to predators,

g_{57} = consumption of primary consumers by invertebrate predators,

g_{58} = consumption of primary consumers by vertebrate predators,

y_{21} = shredder production minus emergence losess,

m_3 = shredder biomass at time k - 1.

y_{23}	Appendix I, page 180	
y_{24}	Appendix I, page 180	
y_{25}	Appendix I, page 181	

	Description	Units
y_{26}	Appendix I, page 181	
$$y_{27} = \begin{Bmatrix} 0 & \textit{if } g_{57} + g_{58} \le 0 \\ y_{26} - \dfrac{g_{12}\left(\dfrac{g_{57}}{g_{57} + g_{58}}\right)}{m_4} & \textit{otherwise} \end{Bmatrix},$$	Collector production minus losses to emergence and invertebrate predation	$g\ g^{-1}$

where

g_{12} = collector losses to predators,

g_{57} = consumption of primary consumers by invertebrate predators,

g_{58} = consumption of primary consumers by vertebrate predators,

y_{26} = collector production minus emergence losses,

m_4 = collector biomass at time k - 1.

y_{28}	Appendix I, page 182	
y_{29}	Appendix I, page 182	
y_{30}	Appendix I, page 182	
y_{31}	Appendix I, page 183	
y_{32}	Appendix I, page 183	
y_{33}	Appendix I, page 183	
y_{34}	Appendix I, page 184	
y_{35}	Appendix I, page 184	
y_{36}	Appendix I, page 185	
y_{37}	Appendix I, page 185	

	Description	Units
y_{38}	Appendix I, page 185	
y_{39}	Appendix I, page 186	
y_{40}	Appendix I, page 186	
y_{41}	Appendix I, page 186	
$y_{42} = x_{15}$,	Diatom biomass	g m^{-2}
$y_{43} = x_{16}$,	Cyanobacteria biomass	g m^{-2}
$y_{44} = x_{17}$,	Chlorophyte biomass	g m^{-2}

Programming Note: Variables y_1, and y_{15} - y_{41} are conditional on $m_i > 0$, where m_i is the state variable value for the i-th process at time $k - 1$. This condition is necessary only when the user sets an initial value of a state variable to zero, thereby turning off the corresponding process for a particular simulation run. In the compiled version of the model that accompanies this documentation, the Pascal code consists of a set of IF statements to correct this problem. Therefore, the problem is only a consideration if the user intends to reprogram the model from this documentation.

6. B Parameters:

Parameters b_1 - b_{114} are the same for Version I and the Herbivory Version of the M & C Stream Model. Standard Run values for these parameters are given in Appendix I, pages 187-192. Parameters and the corresponding Standard Run values listed below are found in the Herbivory Version but not in Version I of the model.

List	Value	Description	In Function
b_{115}	3.0 x 10^{-2}	Grazer demand parameter	g_2
b_{116}	1.75 x 10^{-2}	Grazer demand parameter	g_2
b_{117}	2.5 x 10^{-2}	Grazer demand parameter	g_2
b_{118}	-2.83 x 10^{-2}	Grazer demand parameter	g_2

List	Value	Description	In Function
b_{119}	0.849	Grazer demand parameter	g_2
b_{120}	1	Light energy input multiplier	z_{16}
b_{121}	0.28	Minimum value for the food quality limiting factor	g_{73}

7. Initial Conditions

Input tables corresponding to the Standard Run for Version I of the model (Appendix II) are the same as those used to generate the Standard Run for the Herbivory Version. Initial state variable values required to produce steady state behavior with the standard input tables (Appendix II) and standard parameters (pages 187-192 and 228-229) are listed below.

X List	Value
x_1	Not used
x_2	1.962
x_3	1.304
x_4	2.3
x_5	4.236
x_6	0.194
x_7	0.957
x_8	8.764
x_9	121.095
x_{10}	24.244
x_{11}	30.851
x_{12}	1.145
x_{13}	16.978
x_{14}	0.668
x_{15}	0.957
x_{16}	9.752E-7
x_{17}	1.643E-27

APPENDIX VI

INPUT TABLES FOR THE M & C STREAM MODEL: HERBIVORY VERSION

The input tables for the Standard Run of Version I and the Herbivory Version of the M & C Stream Model are the same, i. e., the tables listed in Appendix II. The tables listed in this section (LITE2000, WRSALOC, and WRFALOC) are the tables that must be used in place of EXLITE (Table 1), SALLOC (Table 4), and FALLOC (Table 5), respectively, in order to run the simulations described in *Example 3* (Herbivory Version, page 83-91).

1. Table: LITE2000

   Unit: ft-c

   Description: Daily mean illumination intensity for one year (360 days)

   Values:

1031	1037	1042	1047	1052	1057	1062	1068	1073	1078	1083	1089
1094	1099	1104	1110	1115	1120	1125	1130	1136	1141	1146	1151
1157	1162	1167	1172	1178	1183	1188	1217	1246	1275	1304	1333
1362	1391	1420	1449	1478	1507	1536	1565	1594	1623	1652	1680
1709	1738	1767	1796	1825	1854	1883	1912	1941	1970	1999	2028
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500

1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
947	961	975	989	1003	946	889	894	899	903	908	913
917	922	927	932	936	941	946	951	955	960	965	969
974	979	984	988	993	998	1003	1007	1012	1017	1022	1026

4. Table: WRSALOC

Unit: g m^{-2}

Description: Slow-conditioned allochthonous input for one year (360 days)

Values:

.0806	.0799	.0792	.0784	.0777	.0770	.0764	.0758	.0752	.0746
.0740	.0735	.0730	.0725	.0720	.0715	.0711	.0707	.0704	.0700
.0696	.0694	.0692	.0689	.0687	.0685	.0683	.0681	.0679	.0677
.0675	.0674	.0673	.0672	.0670	.0669	.0671	.0674	.0676	.0679
.0681	.0684	.0687	.0690	.0693	.0696	.0699	.0702	.0705	.0708
.0711	.0714	.0717	.0720	.0723	.0726	.0729	.0732	.0735	.0738
.0741	.0744	.0747	.0750	.0752	.0755	.0751	.0747	.0743	.0740
.0736	.0730	.0723	.0717	.0711	.0705	.0700	.0695	.0690	.0685
.0679	.0677	.0676	.0674	.0672	.0670	.0668	.0666	.0664	.0662
.0660	.0660	.0660	.0660	.0660	.0660	.0661	.0662	.0663	.0664
.0665	.0664	.0664	.0663	.0663	.0662	.0657	.0652	.0647	.0642
.0637	.0632	.0627	.0621	.0616	.0610	.0605	.0601	.0596	.0591
.0586	.0585	.0583	.0581	.0579	.0578	.0576	.0575	.0573	.0572
.0571	.0570	.0570	.0570	.0570	.0569	.0587	.0605	.0623	.0640
.0658	.0682	.0706	.0730	.0754	.0778	.0806	.0834	.0862	.0890
.0918	.0946	.0974	1.0002	1.0030	1.0058	1.0069	1.0080	1.0092	1.0103
1.0115	1.0126	1.0137	1.0146	1.0157	1.0167	1.0178	1.0188	1.0198	1.0209
1.0219	1.0229	1.0239	1.0249	1.0258	1.0268	1.0265	1.0261	1.0257	1.0254
1.0250	1.0235	1.0219	1.0203	1.0187	1.0172	1.0155	1.0138	1.0121	1.0104
1.0087	1.0070	1.0053	1.0036	1.0019	1.0002	.0986	.0969	.0952	.0935
.0918	.0900	.0883	.0865	.0848	.0830	.0810	.0790	.0771	.0751
.0731	.0712	.0693	.0674	.0655	.0636	.0633	.0631	.0629	.0627
.0624	.0627	.0631	.0634	.0637	.0640	.0644	.0647	.0650	.0653
.0657	.0666	.0676	.0686	.0695	.0705	.0756	.0807	.0859	.0910
.0961	1.0019	1.0077	1.0135	1.0192	1.0250	1.0308	1.0365	1.0422	1.0480
1.0537	1.0593	1.0649	1.0705	1.0761	1.0817	1.0847	1.0876	1.0906	1.0935
1.0964	1.0954	1.0944	1.0934	1.0924	1.0913	1.0903	1.0893	1.0883	1.0873
1.0863	1.0853	1.0842	1.0832	1.0822	1.0812	1.0802	1.0791	1.0781	1.0771
1.0761	1.0757	1.0753	1.0748	1.0744	1.0739	1.0772	1.0805	1.0838	1.0870
1.0903	1.0942	1.0981	2.0020	2.0058	2.0097	2.0136	2.0175	2.0213	2.0252
2.0291	2.0329	2.0368	2.0407	2.0445	2.0484	2.0523	2.0562	2.0600	2.0639
2.0678	2.0695	2.0711	2.0728	2.0745	2.0762	2.0710	2.0659	2.0608	2.0556
2.0505	2.0441	2.0377	2.0313	2.0249	2.0185	2.0121	2.0057	1.0992	1.0928
1.0864	1.0800	1.0736	1.0672	1.0607	1.0543	1.0479	1.0415	1.0351	1.0287

1.0223	1.0178	1.0133	1.0088	1.0043	.0998	.0976	.0953	.0931	.0908
.0886	.0878	.0871	.0863	.0856	.0848	.0840	.0831	.0823	.0814

5. Table: WRFALOC

Unit: g m^{-2}

Description: Fast-conditioned allochthonous input for one year (360 days)

Values:

.0167	.0165	.0164	.0162	.0160	.0158	.0157	.0155	.0153	.0152
.0150	.0149	.0147	.0145	.0144	.0142	.0142	.0141	.0141	.0140
.0139	.0140	.0141	.0142	.0143	.0144	.0144	.0145	.0146	.0147
.0148	.0149	.0150	.0150	.0151	.0152	.0153	.0154	.0156	.0157
.0158	.0158	.0159	.0160	.0161	.0162	.0161	.0161	.0160	.0160
.0160	.0159	.0159	.0158	.0158	.0157	.0157	.0156	.0156	.0155
.0155	.0154	.0153	.0153	.0152	.0152	.0151	.0149	.0148	.0147
.0146	.0145	.0143	.0142	.0140	.0139	.0138	.0137	.0136	.0135
.0135	.0135	.0136	.0136	.0137	.0138	.0138	.0139	.0139	.0140
.0141	.0142	.0143	.0144	.0145	.0146	.0147	.0148	.0149	.0150
.0151	.0152	.0152	.0153	.0153	.0154	.0153	.0152	.0151	.0150
.0149	.0147	.0146	.0145	.0144	.0143	.0141	.0140	.0139	.0138
.0137	.0136	.0135	.0134	.0133	.0132	.0131	.0130	.0129	.0128
.0128	.0127	.0126	.0125	.0125	.0124	.0127	.0129	.0132	.0135
.0138	.0142	.0145	.0149	.0153	.0157	.0160	.0163	.0166	.0168
.0171	.0174	.0176	.0179	.0181	.0184	.0183	.0182	.0181	.0181
.0180	.0179	.0178	.0177	.0176	.0175	.0174	.0173	.0172	.0171
.0170	.0169	.0168	.0167	.0166	.0165	.0164	.0162	.0161	.0160
.0159	.0156	.0154	.0151	.0149	.0146	.0144	.0141	.0138	.0136
.0133	.0130	.0128	.0125	.0122	.0120	.0117	.0114	.0111	.0109
.0106	.0103	.0101	.0098	.0095	.0093	.0090	.0088	.0085	.0082
.0080	.0077	.0075	.0073	.0070	.0068	.0069	.0071	.0073	.0074
.0076	.0079	.0082	.0085	.0088	.0091	.0094	.0097	.0100	.0103
.0106	.0109	.0112	.0115	.0118	.0121	.0124	.0128	.0131	.0135
.0138	.0142	.0145	.0149	.0152	.0156	.0159	.0161	.0164	.0167
.0169	.0170	.0170	.0170	.0171	.0171	.0172	.0173	.0173	.0174
.0175	.0177	.0179	.0181	.0183	.0185	.0187	.0189	.0191	.0193
.0195	.0197	.0199	.0201	.0203	.0205	.0206	.0208	.0210	.0212
.0214	.0218	.0221	.0225	.0228	.0232	.0246	.0259	.0273	.0287
.0300	.0316	.0331	.0346	.0361	.0377	.0392	.0407	.0422	.0438
.0453	.0468	.0483	.0499	.0514	.0529	.0544	.0560	.0575	.0590
.0606	.0616	.0627	.0638	.0649	.0660	.0649	.0638	.0627	.0616
.0605	.0589	.0573	.0557	.0540	.0524	.0508	.0492	.0475	.0459
.0443	.0427	.0411	.0394	.0378	.0362	.0346	.0329	.0313	.0297
.0281	.0271	.0260	.0250	.0240	.0230	.0228	.0226	.0223	.0221
.0218	.0221	.0224	.0227	.0230	.0233	.0220	.0207	.0194	.0181

APPENDIX VII

OUTPUT OF STATE VARIABLE VALUES FOR THE STANDARD RUN OF THE M & C STREAM MODEL: HERBIVORY VERSION

Appendix VII represents the output generated by the Standard Run of the Herbivory Version of the M & C Stream Model (pages 45- 47). In this case, state variables x_2, x_3, x_4, x_5, x_6, x_7, x_{15}, x_{16}, and x_{17} at a time resolution of 30 days were requested by the command file (HERB.CMD). The variables x_{15}, x_{16}, and x_{17} represent the biomasses of diatoms, cyanobacteria, and chlorophytes, and are not present in Version I of the model. The Standard Run is produced by the input tables listed in Appendix II and the parameter values listed in Appendix I and Appendix V. This output was printed from an ouput file (pfile) entitled HERB.OUT.

```
Flex5-PC : A Model Processor

Run No.: 1

Target Level: 1
Target title: Stream Model with Updated Herbivory Subsystem


Initial Conditions

B - Parameters    (121)
      0.000  1.390E-002  5.700E-002      -1.000        0.000       0.114
      0.581  1.970E-004     -94.400    9420.000     1080.000  4.880E-002
 8.830E-002      10.200  2.950E-003       1.070        0.633       1.100
    160.000       1.500       4.000       0.800        1.000       4.000
      0.500       0.000       0.000       3.500        3.500       0.000
 9.950E-002       0.465       0.895       0.560        1.900       1.510
      0.294       2.030  1.280E-004  1.280E-004   1.380E-003  1.380E-003
     -1.000       0.000       0.187  2.330E-003   1.740E-002       0.000
      0.000       0.300       0.860       0.100   1.870E-003  2.500E-003
 2.600E-002  1.880E-002       0.420       0.820   5.000E-002     100.000
      0.000       0.000       0.000       3.000   1.000E-002  2.800E-002
      0.583  1.000E-003       0.500  1.920E-002   2.100E-003       0.700
      0.000  7.400E-003  1.080E-003       0.100        0.400     268.000
      2.950       0.187  1.460E-002  2.960E-002   1.460E-002      15.000
      0.800      12.000       0.350       0.700        0.237    1000.000
   2400.000       0.550       0.180       0.210        0.000       0.300
      0.300       0.300       0.167       1.000   4.460E-003  4.460E-003
 4.460E-003      -1.000  1.440E-004       0.000   5.850E-002  9.110E-004
 1.990E-004  5.850E-002      -1.000      -1.000       -1.000      -1.000
 3.000E-002  1.750E-002  2.500E-002  -2.83E-002        0.849       1.000
      0.280

X - State Variables   (17)
      0.000       1.962       1.304       2.300        4.236       0.194
      0.957       8.764     121.095      24.244       30.851       1.145
```

```
     16.978       0.668       0.957  9.752E-007  1.643E-027

M - Memory    (7)
      0.000       0.000       0.000       0.000       0.000       0.000
      0.000

Table (1): EXLITE
Table (2): XNUTR
Table (3): STRFLOW
Table (4): SALLOC
Table (5): FALLOC
Table (6): GEMER
Table (7): SEMER
Table (8): CEMER
Table (9): PEMER
Table (10): STRTEMP
Table (11): PHOTPER


Print Interval: 30
Variable Headings
    x[2]        x[3]        x[4]        x[5]        x[6]        x[7]
    x[15]       x[16]       x[17]

k = 0
      1.962       1.304       2.300       4.236       0.194       0.957
      0.957  9.752E-007  1.643E-027

k = 30
      1.269       1.858       3.148       4.416       0.356       0.989
      0.989  1.368E-009  2.305E-030

k = 60
      3.667       2.514       3.850       5.031       0.598       8.157
      7.762  4.940E-004       0.395

k = 90
      6.361       2.365       3.820       7.285       0.941       1.032
      1.032  2.228E-005  6.403E-005

k = 120
      1.601       1.960       1.836       9.849       1.266       0.805
      0.805  6.736E-011  1.936E-010

k = 150
      0.626       1.101       1.213       9.323       1.091       0.878
      0.878  5.468E-013  1.571E-012

k = 180
      0.582       0.753       1.077       7.911       0.682       0.854
      0.854  5.307E-015  1.525E-014

k = 210
      0.393       0.649       1.025       6.665       0.410       0.805
      0.805  1.140E-016  3.275E-016

k = 240
      0.603       0.496       1.009       5.778       0.241       1.057
```

1.057	3.634E-018	1.044E-017			

k = 270

0.622	0.361	0.919	5.236	0.129	0.817
0.817	5.799E-020	1.666E-019			

k = 300

1.747	0.499	1.170	4.566	7.429E-002	2.560
2.520	3.942E-002	2.858E-021			

k = 330

2.826	0.842	1.596	4.390	0.113	0.760
0.759	4.523E-004	7.641E-025			

k = 360

1.962	1.305	2.300	4.237	0.194	0.958
0.958	9.754E-007	1.648E-027			

APPENDIX VIII

ANNUAL ENERGY BUDGET TABLES GENERATED FROM THE STANDARD RUN FOR THE HERBIVORY VERSION OF THE M & C STREAM MODEL

The following tables represent output from from BUDGET.COM after STREAM.DMP was introduced as input. In this case, STREAM.DMP was the dump file from the Standard Run of the Herbivory Version of the model (see pages 45- 47). The Standard Run is produced by the input tables listed in Appendix II and the parameter values listed in Appendix I and Appendix V. The output listed in Appendix VIII, which is stored in the file STREAM.TAB, represents two runs, one with grazing and the other with **ix = 0** (without grazing).

MCINTIRE AND COLBY STREAM MODEL

Energy Budget - Annual Resolution

Simulation Run No. Herbivory Version with grazing

Table 1. Bioenergetics of the Major Biological Processes

Property	GRAZE	SRED	COLLECT	V-PRED	I-PRED	ALGAE
Biomass (g/m2):						
Mean	1.932	1.229	1.912	6.218	0.508	1.544
Std Dev	1.874	0.736	1.053	1.880	0.390	1.745
Maximum	9.510	2.586	4.065	9.980	1.293	10.381
Minimum	0.340	0.360	0.903	4.236	0.074	0.576
Production (g/m2/yr):						
Gross Primary						112.556
Net Periphyton						96.149
Secondary	7.214	6.523	9.060	5.587	1.178	
Assimilation (g/m2/yr)	49.550	41.933	52.265	15.801	4.610	
Turnover (times/yr)	3.733	5.307	4.738	0.898	2.321	62.253
Energy Losses (g/m2/yr):						
Respiration/post-mortum decomposition	42.337	35.411	43.205	10.215	3.431	16.408
To invert. predation	1.973	1.550	2.099			
To vert. predation	4.129	2.626	3.969		0.853	
To grazing						68.976
Emergence	1.112	2.363	3.020		0.329	
Vert. mortality				5.586		
Periphyton export:						
Large particle						6.518
Fine particle						17.512
DOM leakage						3.145
Energy Losses (% of assimilation):						
Respiration/post-mortum decompostion	85.44%	84.44%	82.67%	64.64%	74.44%	14.58%
To invert. predation	3.98%	3.70%	4.02%			
To vert. predation	8.33%	6.26%	7.59%		18.51%	
To grazing						61.28%
Emergence	2.24%	5.64%	5.78%		7.13%	
Vert. mortality				35.35%		
Periphyton export:						
Large particle						5.79%
Fine particle						15.56%
DOM leakage						2.79%

Table 2. Bioenergetics of Detrital Processes

Property	FPOM	Total LPOM	Conditioned SLPOM	Conditioned FLPOM	Unconditioned SLPOM	Unconditioned FLPOM
Biomass (g/m2):						
Mean	11.403	88.400	49.475	9.475	28.847	1.096
Std Dev	5.766	54.482	39.623	8.250	14.046	0.691
Maximum	23.282	180.549	122.025	24.244	63.912	3.509
Minimum	4.708	0.000	0.460	0.130	15.312	0.389
Inputs (g/m2/yr):						
Terrestrial SLPOM		401.057				
Terrestrial FLPOM		71.829				
Aquatic (feces):						
Primary consumption	407.071					
Predation	3.584					
Mechanical from LPOM	55.212					
Energy Losses (g/m2/yr):						
Microbial decomposition	130.825	111.932				
To collecting	248.880					
To shredding		232.963				
Export	86.419	72.600				
Mechanical to FPOM		55.212				
Energy Losses (% of total inputs):						
Microbial decomposition	28.08%	23.67%				
To collecting	53.42%					
To shredding		49.26%				
Export	18.55%	15.35%				
Mechanical to FPOM		11.68%				

Table 3. Ecosystem Energy Budget (g/m2/yr)

Property	Inputs	Outputs
Gross Primary Production (GPP)	112.556	
Allochthonous Materials:		
SLPOM	401.057	
FLPOM	71.829	
Drift from Upstream	6.797	
Community Respiration (CR)		393.763
Insect Emergence		6.824
Export/Natural Mortality		191.780
Total	592.239	592.367
Net Gain or Loss	-0.128	
GPP/CR	0.286	

MCINTIRE AND COLBY STREAM MODEL

Energy Budget - Annual Resolution

Simulation Run No. Herbivory Version without grazing

Table 1. Bioenergetics of the Major Biological Processes

Property	GRAZE	SHRED	COLLECT	V-PRED	I-PRED	ALGAE
Biomass (g/m2):						
Mean	0.000	1.289	3.226	5.155	0.294	20.040
Std Dev	0.000	1.007	1.880	1.609	0.217	6.700
Maximum	0.000	3.295	7.322	8.202	0.687	36.180
Minimum	0.000	0.308	1.317	3.169	0.052	9.114
Production (g/m2/yr):						
Gross Primary						529.808
Net Periphyton						308.227
Secondary	0.000	5.633	13.704	4.637	0.404	
Assimilation (g/m2/yr)	0.000	42.001	88.764	13.140	2.395	
Turnover (times/yr)	0.000	4.371	4.249	0.900	1.374	15.381
Energy Losses (g/m2/yr):						
Respiration/post-mortum decomposition	0.000	36.368	75.060	8.503	1.991	221.581
To invert. predation	0.000	0.722	2.199			
To vert. predation	0.000	2.387	6.087		0.221	
To grazing						0.000
Emergence	0.000	2.546	5.467		0.184	
Vert. mortality				4.632		
Periphyton export:						
Large particle						59.582
Fine particle						162.361
DOM leakage						86.741
Energy Losses (% of assimilation):						
Respiration/post-mortum decompostion	0.00%	86.59%	84.56%	64.71%	83.12%	41.82%
To invert. predation	0.00%	1.72%	2.48%			
To vert. predation	0.00%	5.68%	6.86%		9.24%	
To grazing						0.00%
Emergence	0.00%	6.06%	6.16%		7.68%	
Vert. mortality				35.25%		
Periphyton export:						
Large particle						11.25%
Fine particle						30.65%
DOM leakage						16.37%

Table 2. Bioenergetics of Detrital Processes

Property	FPOM	Total LPOM	Conditioned SLPOM	Conditioned FLPOM	Unconditioned SLPOM	Unconditioned FLPOM
Biomass (g/m2):						
Mean	8.026	88.561	49.760	9.368	28.847	1.096
Std Dev	5.316	58.012	42.027	8.626	14.046	0.691
Maximum	22.569	186.652	126.684	25.027	63.912	3.509
Minimum	2.669	0.000	0.542	0.125	15.312	0.389
Inputs (g/m2/yr):						
Terrestrial SLPOM		401.057				
Terrestrial FLPOM		71.829				
Aquatic (feces):						
Primary consumption	525.259					
Predation	2.665					
Mechanical from LPOM	55.301					
Energy Losses (g/m2/yr):						
Microbial decomposition	91.507	111.405				
To collecting	422.686					
To shredding		233.338				
Export	69.260	72.577				
Mechanical to FPOM		55.301				
Energy Losses (% of total inputs):						
Microbial decomposition	15.69%	23.56%				
To collecting	72.47%					
To shredding		49.34%				
Export	11.88%	15.35%				
Mechanical to FPOM		11.69%				

Table 3. Ecosystem Energy Budget (g/m2/yr)

Property	Inputs	Outputs
Gross Primary Production (GPP)	529.808	
Allochthonous Materials:		
SLPOM	401.057	
FLPOM	71.829	
Drift from Upstream	6.584	
Community Respiration (CR)		546.414
Insect Emergence		8.197
Export/Natural Mortality		455.152
Total	1009.278	1009.763
Net Gain or Loss	-0.485	
GPP/CR	0.970	

APPENDIX IX

MATHEMATICAL DOCUMENTATION FOR THE M & C STREAM MODEL: RIPARIAN VERSION

Introduction

Some of the mathematical documentation for the Riparian Version of the M & C Stream Model is the same as the documentation presented for Version I (Appendix I) and the Herbivory Version (Appendix V) of the model. In this section, the only functions that are written out in full are those that are new to the Riparian Version or have a different mathematical form than their representation in either Version I or the Herbivory Version. When a function in the Riparian Version is identical to that presented for Version I or the Herbivory Version, the user is referred to the corresponding page number where the equation can be found in either Appendix I or Appendix V.

The Riparian Version of the M & C Stream Model is a two-level model in which the process of primary production runs at an hourly time resolution and the rest of the system operates at a time resolution of one day. Communication between the two levels of the model is accomplished by a set of coupling variables that pass information back and forth between the two levels. Technical details of this process are explained in the tutorial on pages 96-102 and summarized in Figure 21. Briefly, the z, x, and g variables in Level 1 (daily resolution) that are needed for functions in Level 2 (hourly resolution) are each made equal to a coupling variable (g variable), and the coupling variables are passed down and treated as parameters (b values) in Level 2. Outputs from Level 2 (y variables) are passed back up to Level 1 and are set equal to the g variables that are needed for functions in Level 1. In addition to the z, x, g, *f*, and *y* variables introduced for Version I and the Herbivory Version of the model, Level 2 of the Riparian Version has one *h* variable. In the FLEX paradigm, *h* functions calculate the new value of x_i for the next time step k + 1; in contrast, *f* functions calculate an increment Δ_i to be added to x_i to update the state variable at time k + 1.

The mathematical documentation presented in the next section is organized into two parts. The first part includes all variables and functions associated with Level 1, and the second part gives the variables and functions that are represented in Level 2. In addition, the coupling structure that links Level 1 with Level 2 is specified at the end of the documentation.

Mathematical Documentation: Level 1

TITLE:	McIntire and Colby Stream Model: Riparian Version
INVESTIGATOR:	C. David McIntire
DATE:	1986-1996
LEVEL:	1
TIME RESOLUTION:	1 day (360 days = 1 year)
QUANTITY MODELED:	Biomass expressed as organic matter (dry weight)

VARIABLES AND FUNCTIONS (Level 1):

1. <u>Level 1 X List</u>

Level 1 X List	Description	Units
x_1	Not used	-
x_2	Grazer biomass	g m^{-2}
x_3	Shredder biomass	g m^{-2}
x_4	Collector biomass	g m^{-2}
x_5	Vertebrate predator biomass	g m^{-2}
x_6	Invertebrate predator biomass	g m^{-2}
x_7	Periphyton biomass	g m^{-2}
x_8	Fine particulate organic matter biomass (FPOM)	g m^{-2}

Level 1 X List	Description	Units
x_9	Conditioned allochthonous biomass - slow rate	g m^{-2}
x_{10}	Conditioned allochthonous biomass - fast rate	g m^{-2}
x_{11}	Unconditioned allochthonous biomass - slow rate	g m^{-2}
x_{12}	Unconditioned allochthonous biomass - fast rate	g m^{-2}
x_{13}	SLPOM conditioning gate	none
x_{14}	FLPOM conditioning gate	none
x_{15}	Diatom biomass	g m^{-2}
x_{16}	Cyanobacteria biomass	g m^{-2}
x_{17}	Chlorophyte biomass	g m^{-2}

2. Level 1 Z Functions (input functions):	Description	Units
z_1	Appendix I: page 150	
z_2	Not used (function in Level 2)	
z_3	Appendix I: page 150	
z_4	Appendix I: page 150	
z_5	Appendix I: page 150	
z_6	Appendix I: page 150	
z_7	Appendix I: page 150	
z_8	Appendix I: page 151	
z_9	Appendix I: page 151	
z_{10}	Appendix I: page 151	
z_{11}	Appendix I: page 151	
z_{12}	Appendix I: page 151	
z_{13}	Appendix I: page 152	
z_{14}	Appendix I: page 152	

	Description	Units
z_{15}	Appendix I: page 152	

3. Level 1 G Functions (intermediate functions):

	Description	Units
g_1	Appendix I: page 153	
g_2	Appendix V: page 214	
g_3	Appendix I: page 154	
g_4	Appendix I: page 154	
g_5	Appendix I: page 154	
g_6	Appendix I: page 154	
g_7	Appendix I: page 155	
g_8	Appendix I: page 155	
g_9	Appendix I: page 155	
g_{10}	Appendix I: page 156	
g_{11}	Appendix I: page 156	
g_{12}	Appendix I: page 156	
g_{13}	Appendix I: page 156	
g_{14}	Not used (function in Level 2)	
g_{15}	Not used (function in Level 2)	
g_{16} *through* g_{18}	Not used	
g_{19}	Appendix I: page 158	
g_{20}	Appendix V: page 215	

	Description	Units
g_{21}	Appendix I: page 159	
g_{22}	Appendix I: page 159	
g_{23}	Appendix I: page 159	
g_{24}	Appendix I: page 160	
g_{25}	Appendix I: page 160	
g_{26}	Appendix I: page 160	
g_{27}	Appendix I: page 161	
g_{28}	Appendix I: page 161	
g_{29}	Appendix I: page 162	
g_{30}	Not used (function in Level 2)	
g_{31}	Not used (function in Level 2)	
$g_{32} = b_{122}x_7(b_{75} + b_{70}z_{15})$,	Fine particle periphyton export	$g\ m^{-2}$

where

$b_{122} = 1,$

$b_{75} = 1.08 \times 10^{-3},$

$b_{70} = 1.92 \times 10^{-2},$

z_{15} = shear stress,

x_7 = periphyton biomass.

$g_{33} = b_{123}x_7(b_{73} + b_{74}z_{15})$,	Large particle periphyton export	$g\ m^{-2}$

where

$b_{123} = 1,$

	Description	Units
b_{73} = 0,		
b_{74} = 7.4 x 10^{-3},		
z_{15} = shear stress,		
x_7 = periphyton biomass.		
g_{34}	Appendix I: page 163	
g_{35}	Appendix I: page 163	
g_{36}	Appendix I: page 164	
g_{37}	Appendix I: page 164	
g_{38}	Appendix I: page 164	
g_{39}	Appendix I: page 164	
g_{40}	Appendix I: page 165	
g_{41}	Appendix I: page 165	
g_{42}	Appendix I: page 165	
g_{43}	Appendix I: page 166	
g_{44}	Appendix I: page 166	
g_{45}	Appendix I: page 166	
g_{46}	Appendix I: page 167	
g_{47}	Appendix I: page 167	
g_{48}	Appendix I: page 167	
g_{49} and g_{50}	Not used	
g_{51}	Appendix I: page 168	
g_{52}	Appendix I: page 168	

	Description	Units
g_{53}	Appendix I: page 168	
g_{54}	Appendix I: page 168	
g_{55}	Appendix I: page 169	
g_{56}	Appendix I: page 169	
g_{57}	Appendix V: page 217	
g_{58}	Appendix V: page 218	
g_{59}	Appendix I: page 171	
g_{60}	Not used (function in Level 2)	
g_{61}	Not used (function in Level 2)	
g_{62}	Not used (function in Level 2)	
g_{63}	Not used (function in Level 2)	
g_{64}	Appendix V, page 220	
g_{65}	Appendix V, page 220	
g_{66}	Appendix V, page 221	
g_{67}	Appendix V, page 221	
g_{68}	Appendix V, page 221	
g_{69}	Appendix V, page 221	
g_{70}	Not used (function in Level 2)	
g_{71}	Not used (function in Level 2)	
g_{72}	Not used (function in Level 2)	
g_{73}	Appendix V, page 222	

	Description	Units
g_{74}	Appendix V, page 222	
$g_{75} = z_{10}$,	Coupling variable	ft

where
z_{10} = stream depth.

$g_{76} = z_7$,	Coupling variable	mg l^{-1}

where
z_7 = suspended load.

$g_{77} = z_3$,	Coupling variable	mg l^{-1}

where
z_3 = nutrient concentration.

$g_{78} = x_7$,	Coupling variable	g m^{-2}

where
x_7 = periphyton biomass.

$g_{79} = z_1$,	Coupling variable	°C

where
z_1 = water temperature.

$g_{80} = z_{14}$,	Coupling variable	none

where
z_{14} = current velocity effect.

	Description	Units
$g_{81} = g_{59}$,	Coupling variable	g m^{-2}

where

g_{59} = leakage of dissolved organic matter from periphyton biomass independent of photosynthesis.

4. Level 1 F Functions (update increments):	Description	Units
f_1	Not used	
f_2	Appendix V, page 222	
f_3	Appendix I, page 172	
f_4	Appendix I, page 172	
f_5	Appendix I, page 173	
f_6	Appendix I, page 173	
f_7	Appendix I, page 173	
f_8	Appendix I, page 174	
f_9	Appendix V, page 223	
f_{10}	Appendix V, page 224	
f_{11}	Appendix I, page 175	
f_{12}	Appendix I, page 175	
f_{13}	Appendix I, page 176	
f_{14}	Appendix I, page 176	
f_{15}	Appendix V, page 224	
f_{16}	Appendix V, page 224	

	Description	Units
f_{17}	Appendix V, page 225	

5. Level 1 Y Functions (output variables):

	Description	Units
$y_i = x_i$, for $i = 2, \ldots\ldots\ldots, 12$	See x list	g m^{-2}
$y_{13} = x_9 + x_{10}$	See x list	g m^{-2}
$y_{14} = x_{11} + x_{12}$	See x list	g m^{-2}
y_1	Appendix I, page 177	
y_{15}	Appendix I, page 177	
y_{16}	Appendix I, page 178	
y_{17}	Appendix V, page 225	
y_{18}	Appendix I, page 178	
y_{19}	Appendix I, page 179	
y_{20}	Appendix I, page 179	
y_{21}	Appendix I, page 179	
y_{22}	Appendix V, page 226	
y_{23}	Appendix I, page 180	
y_{24}	Appendix I, page 180	
y_{25}	Appendix I, page 181	
y_{26}	Appendix I, page 181	
y_{27}	Appendix V, page 227	
y_{28}	Appendix I, page 182	

	Description	Units
y_{29}	Appendix I, page 182	
y_{30}	Appendix I, page 182	
y_{31}	Appendix I, page 183	
y_{32}	Appendix I, page 183	
y_{33}	Appendix I, page 183	
y_{34}	Appendix I, page 184	
y_{35}	Appendix I, page 184	
y_{36}	Appendix I, page 185	
y_{37}	Appendix I, page 185	
y_{38}	Appendix I, page 185	
y_{39}	Appendix I, page 186	
y_{40}	Appendix I, page 186	
y_{41}	Appendix I, page 186	
y_{42}	Appendix V, page 228	
y_{43}	Appendix V, page 228	
y_{44}	Appendix V, page 228	

Programming Note: Variables y_1, and y_{15} - y_{41} are conditional on $m_i > 0$, where m_i is the state variable value for the *i*-th process at time $k - 1$. This condition is necessary only when the user sets an initial value of a state variable to zero, thereby turning off the corresponding process for a particular simulation run. In the compiled version of the model that accompanies this documentation, the Pascal code consists of a set of IF statements to correct this problem. Therefore, the problem is only a consideration if the user intends to reprogram the model from this documentation.

6. Level 1 B Parameters:

To simplify matters, parameters b_1 - b_{121} in Level 1 of the Riparian Version of the model are assigned the same numerical values as values for the Standard Run of the Herbivory Version (see Appendix I and Appendix V). If the user decides to program the model in another language, 14 of the these values can be eliminated in Level 1, because they are used in Level 2 or not needed for either level in the Riparian Version. When the model is run by the FLEX model processor, these values are not used during the calculations in Level 1. The 14 parameters not used in Level 1 of the Riparian Version are listed below along with their corresponding parameters in Level 2 and their functions in Level 1 and Level 2.

Parameter (Level 1)	Parameter (Level 2)	Function (Level 1)	Function (Level 2)
b_{113}	b_1	z_2	z_1
b_{120}	b_2	z_{16}	z_1
b_{68}	b_6	g_{14}	g_1
b_{69}	b_7	g_{14}	g_1
b_{78}	b_8	g_{14}	g_1
b_{71}	b_{10}	g_{15}	g_2
b_{90}	b_9	g_{15}	g_2
b_{91}	b_{11}	g_{15}	g_2
b_{79}	b_{16}	g_{30}	g_7
b_{76}	b_{13}	g_{31}	g_3
b_{77}	b_{14}	g_{31}	g_3
b_{66}	b_{19}	g_{60}	h_5
b_{67}	b_{20}	g_{60}	h_5
b_{43}	not used	z_{17}	not used

The following parameters are in Level 1 of the Riparian Version, but are not found in Version I and the Herbivory Version of the model:

List	Value	Description	In Function
b_{122}	1	Fine particle periphyton export multiplier	g_{32}
b_{123}	1	Large particle periphyton export multiplier	g_{33}

7. Level 1 Initial Conditions:

With the exceptions of EXLITE and PHOTPER, input tables corresponding to the Standard Run of the Riparian Version of the model (Appendix XI) are the same as those used to generate the Standard Run for the Version I and the Herbivory Version. In the case of the Riparian Version, the table of irradiation outputs is LITETAB.RUN (introduced in Level 2), and PHOTPER is not used, because irradiation inputs are introduced at an hourly time resolution. Level 1 initial state variable values required to produce steady state behavior with the standard input tables (Appendix II and Appendix X) and standard parameters (pages 187-192, 228-229, and 251-252) are listed below.

Level 1 X List	Value
x_1	Not used
x_2	1.056
x_3	1.258
x_4	2.357
x_5	3.708
x_6	0.11
x_7	1.244
x_8	7.626
x_9	127.2
x_{10}	25.252
x_{11}	30.851
x_{12}	1.145
x_{13}	16.978
x_{14}	0.668
x_{15}	1.266
x_{16}	0
x_{17}	0

LEVEL: 2

TIME RESOLUTION: 1 hour (16 hours = 1 day)

QUANTITY MODELED: Biomass expressed as organic matter (dry weight)

VARIABLES AND FUNCTIONS (Level 2):

1. Level 2 X List

	Description	Units
x_1	Accumulated periphyton gross primary production	g m^{-2}
x_2	Accumulated diatom gross primary production	g m^{-2}
x_3	Accumulated cyanobacteria gross primary production	g m^{-2}
x_4	Accumulated chlorophyte gross primary production	g m^{-2}
x_5	Export of dissolved organic matter from periphyton	g m^{-2}

2. Level 2 Z Functions (input functions): Description Units

$$z_1 = b_2 \left[\frac{\begin{pmatrix} \text{table choice } LITETAB & \text{if } b_1 < 0, \\ b_1 & \text{otherwise} \end{pmatrix}}{0.2} \right]$$

Light intensity directly above the stream — μmol m^{-2} s^{-1}

where

b_1 = -1,

b_2 = 1.0.

$$z_2 = z_1 \exp[-b_3 0.305 \min(3, \max(0.03, 0.03b_4 + 0.2))] ,$$

Effective light intensity at stream bottom — ft-c

where

z_1 = irradiation intensity,

b_3 = stream depth from Level 1,

b_4 = the suspended load from Level 1.

3. Level 2 G Functions (intermediate functions): Description Units

$$g_1 = \begin{cases} \dfrac{b_8 b_5}{1 + b_8 b_5} & \text{if } b_5 < b_6 \\ 1 - \left(\dfrac{1}{1 + b_6 b_8}\right)\left(\dfrac{b_7 - b_5}{b_7 - b_6}\right) & \text{if } b_6 \leq b_5 < b_7 \\ 1 & \text{if } b_7 \leq b_5 \end{cases}$$

Nutrient limiting effect coefficient for primary production — none

where

$b_6 = 1 \times 10^{-3}$,

$b_7 = 0.5$,

$b_8 = 2.68 \times 10^{2}$,

b_5 = limiting nutrient concentration from Level 1.

$$g_2 = \begin{cases} \dfrac{b_{10} z_2}{1 + b_{10} z_2} & \text{if } z_2 < b_9 \\ 1 - \left(\dfrac{1}{1 + b_9 b_{10}}\right)\left(\dfrac{b_{11} - z_2}{b_{11} - b_9}\right) & \text{if } b_9 \leq z_2 < b_{11} \\ 1 & \text{if } b_{11} \leq z_2 \end{cases}$$

Light limiting effect for primary production — none

where

$b_{10} = 2.1 \times 10^{-3}$,

$b_9 = 1 \times 10^{3}$,

$b_{11} = 2.4 \times 10^{3}$,

z_2 = effective light intensity at the stream bottom.

	Description	Units
$g_3 = \left(\frac{b_{13}b_{12}}{1 + b_{13}b_{12}}\right)\left(\frac{b_{14}b_{15}}{1 + b_{14}b_{15}}\right)$,	Biomass and temperature limiting effects on primary production	none

where

b_{12} = periphyton biomass from Level 1,

b_{13} = 0.1,

b_{14} = 0.4,

b_{15} = water temperature from Level 1.

Note: g_4 *and* g_5 *are written as a series of* IF, THEN, *and* ELSE *statements that must executed in order*

IF z_2 * 0.2 >= 300.0 THEN

IF b_{12} < *2.0* THEN g_4 = *1.00*
ELSE IF b_{12} <= *45.0* THEN
g_4 = *-0.01209* * (b_{12} - *2.0*) + *1.0*
ELSE g_4 = *0.48*

IF b_{12} < *30* THEN g_5 = *0.0*
ELSE IF b_{12} <= *45.0* THEN
g_5 = *0.003* * (b_{12} - *30.0*)
ELSE g_5 = *0.04*

g_4 and g_5 are the proportions of the primary production update increment that are diatoms and cyanobacteria, respectively — none

IF z_2 * *0.2* < *300.0* THEN

IF z_2 * *0.2* >= *30.0* THEN

IF b_{12} < *2.0* THEN g_4 = *1.00*
ELSE IF b_{12} <= *25.0* THEN
g_4 = *-0.02261* * (b_{12} - *2.0*) + *1.00*
ELSE g_4 = *0.48*

	Description	Units

IF b_{12} < 2.0 THEN $g_5 = 0.0$
ELSE IF b_{12} <= 5.0 THEN
$g_5 = 0.06333 * (b_{12} - 2.0)$
ELSE $g_5 = 0.19$

IF $z_2 * 0.2$ <= 150.0 THEN
$g_4 = ((0.004333 * (150.0 - (z_2 * 0.2)))/0.52) * (1.0 - g_4) + g_4$

IF $z_2 * 0.2$ <= 50.0 THEN
$g_5 = -((0.0095 * (50.0 - (z_2 * 0.2)))/0.19) * (g_5) + g_5$
ELSE IF g_5 >= 0.04 THEN
$g_5 = ((0.0006 * (50.0 - (z_2 * 0.2)))/0.15) * (g_5 - 0.04) + g_5$

IF $z_2 * 0.2$ < 30.0 THEN
$g_4 = 1.0$
$g_5 = 0.0$

IF $g_4 + g_5 > 1.0$ THEN
$g_4 = 1.0 - g_5$

$$g_6 = \begin{Bmatrix} (1.0 - g_4 - g_5) & \text{if } g_6 > 1.0E{-15} \\ 0 & \text{otherwise} \end{Bmatrix},$$

Proportion of the primary production update increment that represents chlorophytes — none

where

g_4 = proportion of diatoms,

g_5 = proportion of cyanobacteria.

$$g_7 = 0.937 b_{16} g_3 g_1 g_2 b_{17} ,$$

periphyton gross primary production — $g\ m^{-2}$

where

b_{16} = 2.95,

g_3 = biomass and temperature limiting effect coefficient,

g_1 = nutrient limiting effect,

g_2 = light limiting effect,

	Description	Units
b_{17} = current velocity effect.		

$g_8 = g_4 g_7$, Diatom primary production g m^{-2}

where

g_7 = periphyton primary producition,

g_4 = proportion of periphyton primary production from diatoms.

$g_9 = g_5 g_7$, Cyanobacteria primary production g m^{-2}

where

g_7 = periphyton primary production,

g_5 = proportion of periphyton primary production from cyanobacteria.

$g_{10} = g_6 g_7$, Chlorophyte primary production g m^{-2}

where

g_7 = periphyton primary production,

g_6 = proportion of periphyton primary production from chlorophytes.

$g_{11} = g_7 + x_1$, Updated accumulated periphyton gross primary production g m^{-2}

where

g_7 = periphyton primary production,

x_1 = accumulated periphyton primary production.

4. Level 2 F Functions (update increments):

	Description	Units
$f_1 = g_7$	Periphyton gross primary production update increment	g m^{-2}

where

g_7 = periphyton primary production.

	Description	Units
$f_2 = g_8$	Diatom gross primary production update increment	g m^{-2}

where

g_8 = diatom primary production.

	Description	Units
$f_3 = g_9$	Cyanobacteria gross primary production update increment	g m^{-2}

where

g_9 = cyanobacteria prmary production.

	Description	Units
$f_4 = g_{10}$	Chlorophyte gross primary production update increment	g m^{-2}

5. Level 2 H Functions (update values without accumulation):

	Description	Units
$h_5 = \begin{cases} 0.17g_{11} + b_{18} & \text{if } g_{11} > 6.0, \\ b_{19}(e^{b_{20}g_{11}} - 1) + b_{18} & \text{otherwise} \end{cases}$,	Total export of dissolved organic matter from periphyton	g m^{-2}

where

g_{11} = updated accumulated periphyton primary production,

b_{18} = leakage of dissolved organic matter from periphyton independent of photosynthesis from Level 1,

b_{19} = 2.8 x 10^{-2},

b_{20} = 0.583.

6. Level 2 Y Functions (output variables):

	Description	Units
$y_1 = x_1$	See x list	g m^{-2}
$y_2 = x_2$	See x list	g m^{-2}
$y_3 = x_3$	See x list	g m^{-2}
$y_4 = x_4$	See x list	g m^{-2}
$y_5 = x_5$	See x list	g m^{-2}

7. Level 2 B parameters:

List	Value	Description	In Function
b_1	-1	Constant irradiation input	z_1
b_2	1	Irradiation input multiplier	z_1
b_3	Level 1 z_{10}	Stream depth	z_2
b_4	Level 1 z_7	Suspended load	z_2
b_5	Level 1 z_3	Nutrient concentration	g_1
b_6	1×10^{-3}	Primary production nutrient limiting parameter	g_1
b_7	0.5	Primary production nutrient limiting parameter	g_1
b_8	2.68×10^{2}	Primary production nutient limiting parameter	g_1
b_9	1×10^{3}	Primary production light limiting parameter	g_2
b_{10}	2.1×10^{-3}	Primary production light limiting parameter	g_2
b_{11}	2.4×10^{3}	Primary production light limiting parameter	g_2
b_{12}	Level 1 x_7	Periphyton biomass	g_3, g_4, g_5
b_{13}	0.1	Periphyton biomass limiting parameter	g_3

List	Value	Description	In Function
b_{14}	0.4	Temperature limiting parameter	g_3
b_{15}	Level 1 z_1	Water temperature	g_3
b_{16}	2.95	Maximum rate of primary production expressed as O_2 m^{-2} hr^{-1}	g_7
b_{17}	Level 1 z_{14}	Current velocity effect on primary production	g_7
b_{18}	Level 1 g_{59}	Leakage of dissolved organic matter independent of photosynthesis	h_5
b_{19}	0.028	Periphyton dissolved organic matter export parameter	h_5
b_{20}	0.583	Periphyton dissolved organic matter export parameter	h_5

8. Level 2 Initial Conditions:

In Level 2, initial values for all state variables are set equal to zero. Organic matter from primary production accumulates during each 16-hour day and is updated each hour. At the conclusion of each 16-hour day, the accumulated primary production is passed up to Level 1, and the initial values for all state variables are reset to zero.

Level 2 X List	Value
x_1	0
x_2	0
x_3	0
x_4	0
x_5	0

Mathematical Documentation: Coupling Structure

The coupling structure associated with the Riparian Version of the M & C Stream model is discussed on pages 97- 99 and illustrated in Figure 21 of the tutorial. Below, the coupling structure is summarized by tabulating each variable that is passed from one level to the other, its description, its associated coupling variable or Level 2 output variable, and the corresponding parameter or *g* variable that it represents at the other level.

Level 1 Variable	Description	Coupling Variable	Level 2 Parameter
z_{10}	Stream depth	g_{75}	b_3
z_7	Suspended load	g_{76}	b_4
z_3	Nutrient concentration	g_{77}	b_5
x_7	Periphyton biomass	g_{78}	b_{12}
z_1	Water temperature	g_{79}	b_{15}
z_{14}	Current velocity effect	g_{80}	b_{17}
g_{59}	Leakage of dissolved organic matter from periphyton biomass independent of photosynthesis	g_{81}	b_{18}

Level 2 State Variable	Description	Level 2 Output Variable	Level 1 g-Variable
x_1	Periphyton gross primary production	y_1	g_{30}
x_2	Diatom gross primary production	y_2	g_{70}
x_3	Cyanobacteria gross primary production	y_3	g_{71}
x_4	Chloropyhyte gross primary production	y_4	g_{72}
x_5	Export of dissolved organic matter from periphyton	y_5	g_{60}

APPENDIX X

INPUT TABLES FOR THE M & C STREAM MODEL: RIPARIAN VERSION

Input tables for the Standard Run of Version I and the Riparian Version of the M & C Stream Model are the same with the exception of the tables that introduce irradiation inputs and control photoperiod. In the Riparian Version of the model, the table PHOTPER is not used because irradiation inputs are introduced at an hourly time resolution rather than as daily average values. In this section, only the table of irradiation inputs (LITETAB.RUN) is listed; all other input tables used for the Standard Run of the Riparian Version of the model are listed in Appendix II.

1. Table: LITETAB.RUN

   Unit: μmol quanta m^{-2} s^{-1}

   Description: Irradiation values for one year (360 days) at an hourly time resolution

   Values:

0.0	0.0	0.0	0.0	31.5	94.5	115.5	294.0	357.0	409.5	346.5	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	115.5	294.0	357.0	409.5	346.5	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	115.5	294.0	357.0	409.5	346.5	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	115.5	294.0	357.0	409.5	346.5	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	115.5	294.0	357.0	409.5	346.5	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	115.5	294.0	357.0	409.5	346.5	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	27.3	69.3	159.7	277.2	241.6	222.7	147.0	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	50.4	121.8	178.6	247.9	287.7	306.6	235.3	111.3	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	27.3	39.9	54.6	193.2	380.2	399.1	283.5	65.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	60.9	115.5	157.5	205.8	235.3	216.4	163.8	102.9	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	44.1	136.5	155.4	273.1	218.4	195.3	195.3	98.7	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	48.3	113.4	119.7	224.7	369.6	396.9	245.7	128.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	39.9	54.6	56.7	241.6	355.0	394.8	319.2	58.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	35.7	75.6	151.2	155.4	144.9	121.8	84.0	58.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	54.6	115.5	207.9	262.5	216.4	197.5	113.4	54.6	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	35.7	54.6	90.3	94.5	90.3	67.2	29.4	23.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	35.7	75.6	105.0	119.7	107.1	84.0	73.5	39.9	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	44.1	105.0	157.5	262.5	399.1	336.1	210.1	105.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	44.1	105.0	157.5	262.5	399.1	336.1	210.1	105.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	52.5	87.5	140.7	180.6	249.9	312.9	260.5	113.4	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	73.5	128.1	147.0	266.8	283.5	270.9	159.7	100.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	73.5	128.1	147.0	266.8	283.5	270.9	159.7	100.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	73.5	128.1	147.0	266.8	283.5	270.9	159.7	100.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	73.5	128.1	147.0	266.8	283.5	270.9	159.7	100.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	84.0	172.3	197.5	241.6	264.6	197.5	102.9	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	37.8	105.0	149.1	115.5	107.1	126.0	88.2	81.9	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	75.6	166.0	233.1	224.7	163.8	90.3	58.8	48.3	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	71.4	140.7	268.8	296.1	285.7	388.5	342.4	79.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	81.9	174.3	245.7	304.6	268.8	449.5	268.8	163.8	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	56.7	60.9	117.6	312.9	556.6	405.4	327.6	151.2	52.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	81.9	134.4	281.4	405.4	508.2	510.4	430.6	182.7	71.4	0.0	0.0	0.0
0.0	0.0	0.0	0.0	65.1	134.4	262.5	260.5	247.9	189.0	153.4	90.3	37.8	0.0	0.0	0.0
0.0	0.0	0.0	0.0	46.2	130.2	144.9	191.2	178.6	98.7	113.4	100.8	42.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	69.3	161.7	233.1	297.5	401.1	277.2	199.5	105.0	35.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	35.7	60.9	210.1	352.8	709.8	697.2	562.9	184.9	58.8	0.0	0.0	0.0
0.0	0.0	0.0	0.0	58.8	77.7	239.4	331.8	880.0	693.1	338.1	239.4	56.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	92.4	75.6	249.9	340.2	754.0	707.8	581.8	178.6	29.4	0.0	0.0	0.0
0.0	0.0	0.0	0.0	84.0	180.6	281.4	363.3	447.3	363.3	239.4	174.3	86.1	0.0	0.0	0.0
0.0	0.0	0.0	0.0	56.7	58.8	273.1	338.1	772.9	720.4	598.6	201.6	33.6	0.0	0.0	0.0
0.0	0.0	0.0	0.0	39.9	58.8	275.1	355.0	798.1	716.1	579.7	205.8	37.8	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	65.1	128.1	144.9	155.4	123.9	123.9	94.5	52.5	0.0	0.0	0.0

0.0	0.0	0.0	0.0	98.7	182.7	287.7	369.6	485.2	331.8	220.5	107.1	37.8	0.0	0.0	0.0
0.0	0.0	0.0	0.0	21.0	105.0	210.1	220.5	168.0	157.5	168.0	115.5	73.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	21.0	105.0	210.1	220.5	168.0	157.5	168.0	115.5	73.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	84.0	140.7	147.0	210.1	302.4	163.8	109.2	35.7	16.8	0.0	0.0	0.0
0.0	0.0	0.0	0.0	52.5	94.5	178.6	178.6	241.6	262.5	378.0	346.5	336.1	0.0	0.0	0.0
0.0	0.0	0.0	0.0	52.5	94.5	178.6	178.6	241.6	262.5	378.0	346.5	336.1	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	168.0	357.0	525.1	840.1	756.1	619.6	283.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	168.0	357.0	525.1	840.1	756.1	619.6	283.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	84.0	147.0	178.6	199.5	157.5	252.0	367.6	231.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	84.0	147.0	178.6	199.5	157.5	252.0	367.6	231.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	73.5	94.5	94.5	409.5	819.1	294.0	147.0	168.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	21.0	42.0	52.5	178.6	283.5	493.6	693.1	829.6	546.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	21.0	42.0	52.5	178.6	283.5	493.6	693.1	829.6	546.0	-0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	136.5	199.5	136.5	178.6	168.0	105.0	126.0	73.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	126.0	189.0	189.0	367.6	483.0	430.6	378.0	483.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	52.5	136.5	315.0	210.1	157.5	147.0	126.0	126.0	136.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	63.0	94.5	325.5	745.6	430.6	388.5	441.0	168.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	220.5	283.5	619.6	819.1	787.6	472.6	451.5	189.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	94.5	136.5	199.5	262.5	283.5	241.6	220.5	178.6	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	73.5	168.0	535.6	630.1	577.5	775.0	161.7	94.5	0.0	0.0	0.0
0.0	0.0	0.0	58.8	191.2	294.0	802.3	943.0	966.1	772.9	772.9	476.7	56.7	0.0	0.0	0.0
0.0	0.0	0.0	29.4	52.5	352.8	817.0	959.8	972.4	903.1	695.2	428.4	96.6	0.0	0.0	0.0
0.0	0.0	0.0	33.6	58.8	361.3	749.8	827.5	775.0	665.7	548.2	420.0	111.3	0.0	0.0	0.0
0.0	0.0	0.0	84.0	144.9	266.8	243.6	260.5	476.7	504.1	174.3	134.4	86.1	0.0	0.0	0.0
0.0	0.0	0.0	39.9	90.3	195.3	186.9	207.9	329.8	262.5	214.2	199.5	75.6	0.0	0.0	0.0
0.0	0.0	0.0	67.2	151.2	350.7	583.8	627.9	447.3	325.5	197.5	105.0	75.6	0.0	0.0	0.0
0.0	0.0	0.0	44.1	134.4	418.0	659.4	634.2	525.1	705.7	350.7	193.2	151.2	0.0	0.0	0.0
0.0	0.0	0.0	37.8	100.8	207.9	365.4	600.7	556.6	434.7	310.9	340.2	168.0	50.4	0.0	0.0
0.0	0.0	0.0	44.1	115.5	178.6	235.3	304.6	333.9	363.3	151.2	163.8	77.7	39.9	0.0	0.0
0.0	0.0	0.0	44.1	142.8	220.5	212.1	260.5	315.0	331.8	340.2	207.9	130.2	60.9	0.0	0.0
0.0	0.0	0.0	56.7	140.7	586.0	636.4	520.8	642.7	846.4	741.3	428.4	90.3	29.4	0.0	0.0
0.0	0.0	0.0	90.3	174.3	327.6	924.1	913.6	888.4	413.7	348.7	207.9	151.2	56.7	0.0	0.0
0.0	0.0	0.0	88.2	153.4	697.2	869.5	1037.5	1090.0	947.2	483.0	73.5	35.7	37.8	0.0	0.0
0.0	0.0	0.0	84.0	117.6	663.7	741.3	613.3	252.0	245.7	266.8	281.4	121.8	44.1	0.0	0.0
0.0	0.0	0.0	65.1	176.4	418.0	457.8	823.3	714.1	760.3	292.0	180.6	201.6	39.9	0.0	0.0
0.0	0.0	0.0	115.5	233.1	296.1	279.4	415.8	575.5	327.6	254.2	285.7	203.8	58.8	0.0	0.0
0.0	0.0	0.0	60.9	121.8	735.0	951.4	1062.7	1085.9	1016.5	873.7	657.4	100.8	29.4	0.0	0.0
0.0	0.0	0.0	50.4	132.3	747.6	955.6	1062.7	1079.5	1010.2	861.1	632.2	105.0	33.6	0.0	0.0
0.0	0.0	0.0	56.7	142.8	754.0	949.3	1054.4	1069.0	1001.8	850.6	632.2	113.4	33.6	0.0	0.0
0.0	0.0	0.0	54.6	144.9	758.2	959.8	1062.7	1090.0	1018.6	865.3	644.8	117.6	35.7	0.0	0.0
0.0	0.0	0.0	58.8	172.3	770.8	957.7	1054.4	1073.3	1010.2	814.9	436.9	174.3	58.8	0.0	0.0
0.0	0.0	0.0	119.7	279.4	474.7	258.3	749.8	453.7	132.3	214.2	161.7	69.3	27.3	0.0	0.0
0.0	0.0	42.0	123.9	277.2	380.2	491.5	434.7	575.5	705.7	403.2	224.7	77.7	23.1	0.0	0.0
0.0	0.0	21.0	58.8	168.0	646.8	831.7	651.1	943.0	611.2	237.3	260.5	123.9	25.2	0.0	0.0
0.0	0.0	16.8	23.1	50.4	166.0	329.8	1062.7	1190.8	1008.1	476.7	79.8	31.5	48.3	0.0	0.0
0.0	0.0	31.5	81.9	142.8	214.2	285.7	189.0	121.8	136.5	113.4	237.3	193.2	60.9	0.0	0.0
0.0	0.0	37.8	73.5	319.2	281.4	508.2	833.8	294.0	632.2	466.3	180.6	132.3	39.9	0.0	0.0
0.0	0.0	50.4	132.3	256.2	772.9	693.1	718.3	617.5	655.3	178.6	359.1	58.8	16.8	0.0	0.0
0.0	0.0	14.7	18.9	18.9	56.7	86.1	102.9	86.1	102.9	176.4	119.7	67.2	46.2	0.0	0.0
0.0	0.0	16.8	27.3	94.5	166.0	514.5	241.6	758.2	594.4	325.5	268.8	102.9	100.8	0.0	0.0
0.0	0.0	21.0	35.7	52.5	98.7	142.8	273.1	676.3	485.2	310.9	193.2	84.0	90.3	0.0	0.0
0.0	0.0	50.4	123.9	119.7	174.3	564.9	359.1	438.9	800.2	848.5	338.1	138.6	39.9	0.0	0.0
0.0	0.0	42.0	149.1	273.1	663.7	663.7	646.8	690.9	796.0	735.0	249.9	222.7	56.7	0.0	0.0
0.0	0.0	35.7	130.2	130.2	468.4	558.6	1237.0	1006.0	728.7	478.9	296.1	180.6	115.5	0.0	0.0
0.0	0.0	33.6	63.0	548.2	932.5	1108.9	1169.8	1262.3	655.3	546.0	745.6	214.2	39.9	0.0	0.0
0.0	0.0	35.7	67.2	569.2	938.8	1113.1	1213.9	1230.8	1150.9	993.4	764.5	231.0	39.9	0.0	0.0
0.0	0.0	44.1	155.4	447.3	751.9	880.0	287.7	317.2	352.8	231.0	109.2	90.3	58.8	0.0	0.0
0.0	0.0	33.6	71.4	201.6	355.0	430.6	359.1	243.6	260.5	166.0	117.6	115.5	46.2	14.7	0.0
0.0	0.0	23.1	56.7	96.6	136.5	155.4	222.7	201.6	134.4	88.2	102.9	54.6	33.6	14.7	0.0
0.0	0.0	21.0	52.5	77.7	142.8	186.9	203.8	279.4	197.5	296.1	151.2	105.0	39.9	18.9	0.0
0.0	0.0	16.8	52.5	102.9	485.2	598.6	821.2	1291.6	1075.3	726.7	596.4	189.0	77.7	18.9	0.0
0.0	0.0	48.3	138.6	743.5	985.0	1155.2	1251.7	1270.6	1077.4	523.0	571.2	283.5	105.0	31.5	0.0
0.0	0.0	46.2	94.5	149.1	730.9	564.9	632.2	464.1	667.9	310.9	296.1	193.2	109.2	25.2	0.0
0.0	0.0	109.2	218.4	333.9	369.6	401.1	567.1	808.6	548.2	737.2	438.9	310.9	126.0	31.5	0.0
0.0	0.0	47.8	220.2	774.7	955.3	1088.3	1250.3	1254.5	1163.1	1003.1	801.7	249.2	54.0	16.6	0.0
0.0	0.0	42.6	257.9	777.6	994.8	1157.2	1242.4	1254.6	1183.6	1033.4	814.1	223.3	40.6	12.2	0.0
0.0	0.0	50.1	285.0	768.7	987.4	1146.0	1232.2	1244.2	1137.3	1025.5	814.8	212.8	36.1	10.1	0.0
0.0	0.0	53.5	285.6	739.8	962.0	1134.6	1198.1	1206.0	1130.6	983.8	775.5	214.2	43.6	13.9	0.0
0.0	0.0	54.2	294.4	722.4	933.6	1073.0	1142.7	1133.0	1094.4	949.0	662.4	209.2	81.3	27.1	0.0
0.0	15.3	78.5	170.3	514.7	941.4	1081.2	1144.3	1161.5	1096.4	951.0	746.3	244.9	61.3	21.1	0.0
0.0	20.8	60.5	310.0	621.8	795.7	1005.6	1054.7	984.8	948.9	765.5	538.7	262.8	68.0	17.0	0.0
0.0	16.6	55.3	337.3	678.5	875.6	1025.0	1115.3	1135.6	1067.4	927.3	741.1	228.6	59.0	27.7	0.0
0.0	29.1	112.9	322.1	651.6	830.0	924.7	944.7	941.1	728.1	537.0	395.0	225.7	74.6	14.6	0.0
0.0	12.6	34.1	84.5	278.5	300.1	555.2	659.4	700.8	672.1	364.7	217.4	247.9	97.0	28.7	0.0
0.0	21.0	54.2	388.6	691.3	878.6	1015.1	1109.6	1111.3	999.4	866.3	721.0	241.5	50.8	19.3	0.0
0.0	29.4	124.3	243.5	461.1	654.5	882.5	873.8	763.2	880.7	759.8	507.7	262.5	134.7	50.1	0.0
0.0	27.2	95.4	212.9	504.2	749.6	863.7	889.2	848.3	810.9	756.4	538.3	277.7	114.1	51.1	0.0
0.0	24.8	74.5	407.6	576.6	588.2	734.0	463.9	906.3	869.8	384.4	233.6	160.7	92.8	36.4	0.0
0.0	18.0	44.1	94.7	161.7	281.0	532.5	472.1	532.5	339.8	411.7	604.4	183.0	68.6	22.9	0.0
0.0	19.3	56.4	428.3	669.9	837.3	961.2	1025.7	1028.9	969.3	851.8	676.3	214.2	38.6	17.7	0.0
0.0	29.7	78.2	364.3	636.4	800.5	916.2	966.2	953.7	919.3	802.1	641.1	197.0	36.0	17.2	0.0
0.0	27.7	110.9	329.6	568.3	720.8	722.3	750.0	754.6	827.0	730.0	599.1	228.0	90.9	29.2	0.0
0.0	25.8	66.8	113.8	245.7	291.2	397.4	837.3	650.7	405.0	232.1	248.8	192.7	104.7	37.9	0.0
0.0	33.8	88.2	123.5	361.7	289.6	549.9	276.4	397.0	426.3	335.2	186.7	242.6	119.1	30.9	0.0
0.0	14.4	34.7	75.2	91.1	143.2	123.0	108.5	230.0	257.5	238.7	110.0	105.6	55.0	20.3	0.0
0.0	22.8	66.9	200.7	308.9	314.6	465.5	427.1	324.6	448.4	368.7	344.5	220.6	95.3	44.1	0.0
0.0	28.9	78.5	150.1	498.4	607.2	732.5	728.4	656.7	571.4	446.1	567.2	207.9	46.8	23.4	0.0
0.0	28.4	105.6	358.7	445.3	740.4	778.2	900.0	697.0	491.3	441.2	483.2	238.2	71.7	35.2	0.0
0.0	41.2	121.1	317.9	357.8	496.1	593.3	653.1	504.1	573.3	681.0	512.1	206.2	102.4	29.2	0.0

0.0	42.4	110.4	301.6	512.1	516.0	734.1	785.5	831.7	481.3	458.2	533.9	202.8	43.6	20.5	0.0
0.0	35.3	102.1	322.6	494.0	632.6	733.4	787.6	791.4	693.1	574.6	402.0	195.3	65.5	31.5	1.2
0.0	27.2	112.6	316.6	334.0	526.9	477.4	671.6	660.4	589.9	502.1	356.2	207.8	110.1	48.2	2.5
0.0	14.3	38.1	91.6	142.8	207.1	239.2	313.0	397.5	486.7	210.6	167.8	132.1	89.2	40.4	4.7
0.0	28.0	78.2	206.5	193.7	366.4	406.1	380.4	423.6	358.2	351.2	267.2	127.2	77.0	22.1	3.5
0.0	24.0	106.3	348.7	491.7	608.3	690.7	737.5	739.8	697.5	618.6	494.0	185.2	34.3	18.3	1.1
0.0	24.1	110.8	337.8	456.3	565.9	594.5	653.7	649.3	517.7	510.0	379.5	188.7	95.4	38.4	2.2
0.0	15.0	98.8	265.1	366.0	546.4	596.9	662.3	661.2	597.9	411.1	448.7	180.3	67.6	29.0	3.2
0.0	26.2	66.2	194.3	386.5	491.4	617.4	662.6	677.3	468.4	560.7	451.5	188.0	32.5	25.2	4.2
0.0	36.1	117.4	282.0	399.4	489.7	481.6	600.1	623.1	550.9	508.7	424.5	176.6	30.1	18.1	2.0
0.0	24.5	103.9	299.9	410.7	504.8	578.3	612.6	613.5	590.0	518.5	423.4	179.3	30.4	14.7	1.0
0.0	24.9	83.2	163.6	245.9	365.5	444.9	527.2	601.8	562.6	498.5	408.5	177.9	38.3	26.8	5.7
0.0	29.1	71.0	152.0	193.8	192.0	273.9	235.7	235.7	142.9	150.2	156.5	96.5	63.7	32.8	4.6
0.0	21.3	61.2	99.3	128.6	180.9	166.7	122.4	283.7	141.0	128.6	152.5	103.7	70.1	28.4	6.2
0.0	29.3	95.0	237.4	372.1	201.2	202.9	351.4	402.3	331.6	444.7	311.7	170.9	37.1	16.4	1.7
0.0	20.4	84.9	238.5	306.3	395.3	458.2	477.0	547.2	454.9	435.3	358.5	173.9	73.5	35.9	5.7
0.0	19.8	87.3	246.0	343.5	424.5	485.6	526.0	575.2	520.5	455.4	384.8	154.7	71.4	19.8	0.8
0.0	25.4	79.3	87.0	160.2	235.7	151.7	300.3	145.5	206.4	379.6	202.5	132.5	34.6	15.4	6.9
0.0	15.2	48.5	94.8	137.5	188.1	280.0	414.5	405.8	453.6	397.1	322.6	151.2	27.5	15.2	2.9
0.0	16.8	42.0	109.9	294.7	366.8	423.5	454.3	462.8	321.3	119.0	219.8	148.4	33.6	19.6	4.2
0.0	21.7	69.0	154.3	248.4	199.0	363.4	458.8	282.2	253.1	161.1	54.8	62.9	27.8	16.2	4.7
0.0	12.0	37.8	73.1	133.6	174.5	233.8	215.5	183.4	154.4	143.0	62.4	70.6	39.7	10.7	3.8
5.5	18.2	40.0	61.9	106.8	194.1	199.6	146.8	202.0	164.4	111.6	171.1	64.9	29.7	12.1	4.2
3.5	12.3	42.6	73.5	166.3	167.4	274.8	263.1	276.5	206.5	148.8	163.9	156.3	44.9	19.8	3.5
4.3	21.5	37.0	91.8	172.8	175.0	230.3	288.2	312.9	220.6	260.8	198.1	134.2	28.5	11.8	2.7
3.6	13.4	46.7	162.7	220.7	275.2	311.6	330.1	328.6	313.2	278.3	232.6	119.6	16.4	9.2	2.0
2.9	11.8	44.6	157.8	215.1	262.7	298.4	318.0	321.5	303.3	266.6	217.1	112.7	14.2	7.8	1.5
2.7	10.6	41.7	136.6	187.5	232.3	263.4	282.4	276.7	265.6	235.9	192.4	100.2	15.1	8.4	2.2
3.4	14.3	34.0	65.1	113.0	170.1	188.6	195.7	234.0	190.7	126.4	25.2	3.8	1.7	4.2	2.1
2.0	3.6	7.5	11.1	22.6	35.3	42.1	75.4	101.6	83.3	70.6	38.9	30.9	15.9	6.0	2.8
2.4	8.1	18.2	27.0	78.1	83.7	73.5	31.9	38.2	26.6	34.0	27.3	18.6	15.4	7.3	2.8
2.0	8.2	26.8	70.2	123.2	172.2	196.4	208.8	209.4	197.7	176.1	145.1	78.7	11.1	6.9	2.3
2.1	6.7	16.7	30.9	127.7	159.3	181.4	193.8	194.8	184.4	164.1	135.3	73.7	9.7	6.1	1.8
1.8	7.2	24.1	77.8	108.1	133.0	151.4	160.9	162.7	152.5	134.5	113.2	62.1	8.0	4.9	1.3
1.6	6.1	21.2	72.1	96.8	120.2	135.8	144.5	146.3	139.3	123.2	101.3	56.5	9.3	5.1	1.4
1.6	6.3	20.8	68.8	94.3	116.4	134.4	144.7	149.1	144.9	68.4	10.5	1.6	0.5	0.9	1.4
1.6	5.4	16.3	29.2	57.9	90.3	87.5	121.4	125.8	134.2	39.7	7.9	1.4	3.5	4.9	1.4
1.2	2.6	5.6	15.6	27.1	53.2	32.9	22.6	45.5	97.8	109.4	95.4	61.6	24.3	12.6	2.8
1.6	6.8	20.8	73.3	97.5	118.1	135.6	142.6	142.6	137.0	127.9	106.9	65.8	14.0	7.2	1.2
1.4	6.1	20.5	69.5	99.2	120.9	138.2	149.6	151.0	142.3	125.1	103.8	58.6	7.2	4.4	1.4
1.9	6.5	22.9	60.4	37.8	54.8	42.0	82.6	98.5	120.9	64.2	20.3	7.9	6.1	5.8	1.9
1.6	10.3	20.1	67.9	90.8	116.2	132.6	130.7	130.9	109.7	95.4	79.1	48.1	21.7	11.4	2.6
2.1	6.3	17.0	15.6	19.6	37.3	56.7	18.0	14.0	18.4	16.6	19.8	14.0	7.5	7.0	2.6
1.4	5.4	16.1	27.1	40.4	48.5	105.2	136.3	75.1	40.4	47.4	22.4	16.3	5.8	3.0	1.2
1.6	6.1	17.0	22.9	32.4	59.3	57.9	62.5	62.5	27.1	19.6	10.3	9.6	8.6	3.3	1.4
2.1	9.3	17.7	39.0	62.3	102.0	57.6	81.0	73.7	33.4	29.6	21.5	12.6	7.2	4.4	1.4
1.4	4.4	9.3	10.0	37.1	73.7	82.1	73.3	125.8	31.3	49.5	63.5	25.9	22.9	12.1	2.3
1.4	6.1	13.8	28.9	51.6	97.1	142.8	151.2	150.8	143.5	128.8	102.0	61.6	10.3	8.4	3.0
1.4	4.0	9.1	19.8	24.7	28.5	85.6	67.9	40.6	23.3	10.7	13.1	11.0	9.8	8.2	2.6
1.4	5.4	14.2	43.2	70.0	86.8	110.8	114.1	116.4	137.0	86.6	59.0	49.9	21.2	8.6	3.3
1.6	6.3	21.5	46.9	65.3	87.3	116.4	94.0	102.2	40.6	34.8	33.4	16.3	19.6	9.6	1.9
1.6	6.5	27.3	72.6	74.2	119.5	148.2	102.2	152.4	127.0	108.0	95.7	60.4	9.1	7.0	2.6
1.4	5.4	20.3	71.6	96.1	111.1	125.6	137.9	136.1	110.1	112.9	78.9	53.7	24.5	15.6	2.6
1.2	5.8	15.6	53.0	92.4	77.5	103.6	137.5	144.9	90.8	126.3	82.8	44.6	26.8	10.7	2.1
0.7	5.8	19.1	71.2	97.1	120.4	137.7	147.0	149.3	142.6	126.3	103.8	57.9	8.4	4.9	1.6
1.2	5.6	19.1	56.5	94.7	118.8	124.4	97.3	116.0	132.6	117.6	94.3	53.9	16.8	9.6	2.1
1.2	5.4	18.9	68.4	95.2	119.5	136.3	145.6	137.5	136.8	123.9	100.8	56.2	10.7	5.4	1.4
1.2	5.4	19.1	66.0	92.9	116.0	133.5	143.3	145.4	138.8	124.9	109.4	56.0	9.8	6.3	0.9
1.2	5.1	19.6	65.8	94.0	116.7	133.7	143.3	145.8	136.8	101.5	97.5	43.6	10.0	5.4	1.9
1.2	5.1	19.4	63.9	88.7	43.2	52.7	29.2	47.1	57.6	57.6	48.1	31.3	13.3	7.5	2.6
1.2	5.8	19.1	46.4	97.3	90.1	64.4	89.4	81.2	123.7	48.3	79.1	56.5	8.6	4.7	0.9
1.2	6.5	14.7	60.7	81.0	126.3	139.1	127.0	159.2	134.0	84.5	107.6	55.3	8.9	7.5	0.9
1.2	4.9	20.5	66.5	95.0	119.3	132.8	144.0	147.0	131.6	125.6	98.9	53.4	8.2	4.7	0.9
0.9	5.4	19.4	60.7	92.4	111.5	133.5	145.8	147.7	139.8	124.2	101.0	50.2	7.9	5.4	0.9
0.9	4.7	19.6	63.5	86.8	115.0	132.6	142.6	144.5	137.7	121.8	100.3	50.9	6.8	4.0	0.9
0.9	4.4	18.0	64.2	92.6	115.3	132.6	142.3	144.2	137.2	122.5	101.0	50.6	6.5	4.0	0.7
0.9	4.4	18.0	65.3	93.1	115.7	132.8	143.3	143.8	136.5	121.4	100.6	50.9	10.0	4.9	0.9
0.9	6.1	12.1	20.5	43.4	108.0	135.1	145.6	147.3	140.0	125.1	103.4	51.1	6.3	3.5	0.5
0.9	4.2	16.8	68.4	97.5	120.4	137.9	146.6	146.1	137.9	121.6	99.2	48.8	7.7	4.2	0.5
0.7	4.0	16.3	66.7	95.9	118.8	136.3	145.6	145.8	136.8	120.0	97.8	51.8	19.8	9.6	0.9
0.9	4.7	16.6	61.4	89.6	112.7	130.2	138.8	140.3	133.3	118.1	95.7	43.6	9.6	5.4	1.2
0.9	4.7	15.2	58.8	87.0	110.1	128.1	138.2	139.8	132.6	117.6	96.1	42.2	8.9	5.6	1.2
0.9	6.3	16.3	58.8	83.8	68.4	104.8	124.6	155.2	134.7	116.2	93.8	40.6	8.9	4.9	0.9
0.9	4.7	14.9	41.1	82.6	107.3	119.3	141.0	89.1	35.5	31.5	81.0	55.8	21.9	11.7	2.3
0.9	4.2	11.9	37.6	85.2	108.7	116.7	134.2	138.6	132.8	107.6	89.1	50.9	17.5	7.5	1.2
1.2	2.3	5.4	13.3	25.2	70.2	127.4	136.8	139.8	132.3	116.2	94.0	40.1	9.6	5.8	1.6
1.2	2.3	9.6	20.8	29.6	32.2	65.3	88.7	96.1	134.4	61.4	44.6	26.1	12.6	5.1	1.4
0.9	2.8	11.4	24.3	75.6	107.8	132.8	142.1	144.7	137.7	122.3	99.9	39.4	6.5	3.5	0.2
0.9	3.7	14.5	28.5	40.1	33.1	31.3	41.5	50.6	51.6	37.1	27.8	13.8	8.9	6.3	1.2
0.0	4.9	16.3	56.0	75.6	91.0	86.6	78.4	47.6	40.4	30.8	21.7	12.8	21.0	7.2	0.0
0.0	4.0	14.5	47.8	59.3	76.1	81.4	68.1	64.6	78.4	55.3	43.4	25.9	14.5	7.0	1.2
0.0	2.6	10.7	27.3	58.3	102.0	129.1	137.2	140.7	134.7	114.6	89.4	36.4	8.2	3.3	0.0
0.0	3.5	10.3	53.4	82.6	107.8	127.7	136.5	138.6	131.8	116.0	94.0	35.9	6.8	4.0	0.0
0.0	3.5	10.0	48.5	78.9	104.3	125.1	134.9	134.9	126.0	109.7	86.6	34.1	7.9	4.0	0.0
0.0	4.4	11.4	46.7	72.6	77.5	84.2	114.8	115.3	115.0	98.9	62.1	36.4	15.2	1.9	0.2
0.0	1.6	6.1	9.6	22.9	66.3	26.6	54.6	46.2	128.3	113.2	90.3	34.5	7.9	6.1	0.7
0.0	3.5	4.9	13.3	24.5	28.7	68.4	34.5	29.6	22.9	16.3	11.2	9.1	7.5	3.0	0.9
0.0	3.3	12.6	29.2	51.1	49.2	55.1	45.5	54.8	66.3	52.3	42.7	34.8	16.3	7.0	0.2
0.0	1.6	10.5	27.1	35.7	64.6	62.3	67.0	99.2	128.1	80.0	58.8	31.3	14.0	4.4	0.0

0.0	3.5	11.0	24.3	77.2	108.7	126.7	136.1	137.5	130.0	113.6	91.0	34.1	5.4	2.6	0.0
0.0	2.6	6.5	46.4	84.9	108.5	126.7	136.5	133.3	130.9	115.0	64.6	31.5	11.4	3.7	0.5
0.0	2.3	8.2	21.5	33.4	51.6	45.7	56.7	46.0	43.6	32.0	33.8	25.7	20.5	6.3	0.0
0.0	2.3	10.3	40.4	63.9	103.4	126.5	135.8	137.5	129.1	112.7	89.4	30.1	7.7	2.8	0.0
0.0	3.0	8.2	38.7	81.7	106.4	124.6	134.9	135.3	128.3	112.5	89.4	29.6	5.6	2.3	0.0
0.0	2.6	7.2	37.3	81.9	105.9	123.7	133.0	133.7	125.8	109.2	85.2	28.9	6.5	2.3	0.0
0.0	2.6	7.2	35.2	81.0	105.0	122.5	131.2	131.4	123.2	107.1	83.5	28.5	10.0	3.0	0.0
0.0	2.8	10.7	37.6	51.1	77.9	120.2	115.0	89.8	93.8	95.0	86.3	31.7	11.2	2.3	0.5
0.0	2.3	8.6	35.9	75.6	94.0	116.9	130.7	131.6	122.8	104.5	82.1	25.0	6.5	2.3	0.0
0.0	2.3	7.7	30.1	76.5	89.6	105.9	125.6	127.2	119.0	103.4	81.4	24.0	5.8	1.9	0.0
0.0	2.1	6.3	29.2	79.8	104.3	123.0	133.5	134.0	124.4	108.3	85.2	23.8	4.7	1.4	0.0
0.0	1.9	5.8	28.7	82.1	106.6	124.2	133.3	133.0	124.4	106.9	81.7	22.9	5.1	1.6	0.0
0.0	2.3	7.0	27.5	75.8	99.2	113.9	110.4	93.3	77.2	108.7	81.2	22.9	5.8	1.6	0.0
0.0	1.9	6.3	22.9	77.5	101.0	118.3	129.8	132.6	128.1	107.6	82.4	21.9	5.1	1.2	0.0
0.0	1.9	8.2	20.1	78.6	103.6	120.4	130.9	130.7	123.5	106.4	83.5	21.7	4.9	1.4	0.0
0.0	2.3	10.7	22.4	70.0	104.1	121.1	132.6	132.6	124.6	107.6	84.5	20.5	4.7	1.2	0.0
0.0	1.6	5.6	12.8	79.3	105.7	122.8	133.0	133.0	123.7	102.0	74.4	21.7	10.0	1.9	0.0
0.0	1.2	4.4	9.3	11.7	22.9	40.6	45.5	102.0	73.7	34.3	36.9	18.0	8.9	1.4	0.0
0.0	1.4	5.6	9.8	73.3	100.3	118.6	127.9	128.1	120.0	93.6	76.5	16.8	4.4	1.2	0.0
0.0	1.4	5.1	9.6	73.0	102.2	119.3	129.3	129.5	120.9	102.9	77.7	16.3	4.2	0.9	0.0
0.0	1.4	4.7	9.1	68.8	98.2	116.2	125.1	126.0	120.7	102.2	68.8	23.6	8.2	1.2	0.0
0.0	1.2	4.0	9.8	19.1	29.9	12.1	11.7	14.5	31.5	44.8	42.7	26.6	13.3	1.6	0.0
0.0	1.6	10.0	21.5	62.5	103.4	119.3	127.2	126.5	116.7	100.8	76.3	13.5	4.0	0.2	0.0
0.0	1.4	5.4	9.1	65.8	99.2	116.2	125.3	124.4	114.6	95.9	72.6	14.0	4.2	0.2	0.0
0.0	1.4	8.4	17.3	49.7	87.5	108.5	118.6	122.3	113.4	91.9	72.8	10.7	3.5	0.0	0.0
0.0	1.4	7.5	14.5	54.6	92.2	103.4	117.4	123.2	113.9	94.7	70.2	10.5	4.0	0.2	0.0
0.0	1.2	5.1	9.1	56.0	96.4	112.9	122.3	121.6	112.2	95.2	71.2	10.0	3.5	0.0	0.0
0.0	1.9	7.5	17.0	25.2	11.4	13.3	27.8	25.0	14.7	12.4	7.5	19.6	9.8	1.2	0.0
0.0	1.4	7.9	19.1	23.6	43.2	62.1	96.6	88.4	113.4	61.4	67.7	13.5	3.0	0.2	0.0
0.0	1.6	7.2	21.0	21.0	28.0	35.7	18.9	20.1	21.5	21.0	13.1	7.5	3.3	1.2	0.0
0.0	0.0	3.5	7.9	31.0	42.7	60.2	58.1	84.7	22.2	95.9	57.2	10.0	5.4	0.5	0.0
0.0	0.0	4.4	8.4	46.4	95.9	116.4	113.2	85.9	74.0	30.3	28.9	18.0	6.5	0.5	0.0
0.0	0.0	4.2	8.2	42.5	95.7	112.9	121.4	121.1	110.6	92.2	66.7	7.9	4.0	0.0	0.0
0.0	0.0	4.2	7.7	40.8	94.7	111.3	120.0	119.5	109.7	91.5	59.5	7.0	2.1	0.0	0.0
0.0	0.0	4.4	8.2	40.1	93.6	109.9	122.1	123.9	112.5	90.5	46.2	8.4	4.7	0.2	0.0
0.0	0.0	5.1	15.4	36.6	89.6	100.1	84.9	107.8	107.6	56.5	16.8	8.2	2.6	0.0	0.0
0.0	0.0	5.9	13.1	45.7	94.0	73.2	115.8	96.8	51.9	20.0	12.8	12.3	3.9	0.8	0.0
0.0	0.0	8.5	21.5	36.4	76.1	74.9	117.1	107.1	90.4	27.6	13.9	6.4	2.4	0.6	0.0
0.0	0.0	3.3	12.7	30.7	44.1	45.4	80.4	91.2	71.9	48.0	37.9	25.5	7.2	0.0	0.0
0.0	0.0	6.0	13.7	48.7	131.6	153.7	163.5	154.7	131.6	121.8	70.7	21.0	6.3	0.0	0.0
0.0	0.0	6.3	17.1	55.9	110.7	159.1	180.9	188.0	172.6	140.0	73.0	11.1	4.0	0.0	0.0
0.0	0.0	6.7	13.9	54.2	156.7	184.8	199.5	198.7	180.2	145.7	73.1	11.3	5.9	0.0	0.0
0.0	0.0	5.8	26.6	53.7	124.1	96.2	172.0	208.4	188.0	162.3	88.2	23.0	8.4	0.0	0.0
0.0	0.0	4.9	16.7	25.0	49.0	47.5	37.3	37.3	41.7	34.8	43.6	27.9	6.9	1.5	0.0
0.0	0.0	4.6	25.7	22.1	32.8	26.7	48.8	46.2	39.5	56.5	51.3	27.7	9.2	0.0	0.0
0.0	0.0	4.8	28.5	75.7	137.9	45.6	46.7	50.5	59.0	55.3	35.4	19.8	2.7	0.0	0.0
0.0	0.0	8.8	23.3	43.2	65.9	88.1	93.9	95.7	61.9	47.3	49.6	9.9	3.5	0.0	0.0
0.0	0.0	10.3	28.5	40.0	121.3	252.8	281.5	241.5	171.1	44.3	47.9	32.8	7.3	0.0	0.0
0.0	0.0	6.9	25.2	82.5	212.3	270.3	288.6	289.8	260.8	206.7	81.3	12.6	2.5	0.0	0.0
0.0	0.0	9.5	39.9	81.9	228.7	287.6	310.0	305.2	272.7	214.5	83.2	12.8	2.7	0.0	0.0
0.0	0.0	14.0	44.1	88.9	95.9	102.9	70.7	53.2	47.6	35.7	18.9	9.1	4.2	0.0	0.0
0.0	0.0	11.6	45.6	77.4	226.4	266.9	316.9	316.9	218.5	107.1	65.8	29.7	3.6	0.0	0.0
0.0	0.0	6.9	26.2	47.0	107.8	181.7	202.5	108.6	168.7	124.7	107.1	36.2	5.4	0.0	0.0
0.0	0.0	11.1	38.1	50.0	256.3	322.1	345.1	305.5	219.0	223.8	92.0	18.3	3.2	0.0	0.0
0.0	0.0	5.7	15.5	11.4	17.1	31.0	33.5	71.0	76.8	71.9	26.1	22.0	7.3	0.0	0.0
0.0	0.0	12.1	26.8	50.9	89.8	69.9	81.2	88.9	82.0	49.2	26.8	16.4	4.3	0.0	0.0
0.0	0.0	8.0	37.2	93.1	149.9	281.1	233.2	185.3	153.4	129.5	80.7	39.0	7.1	0.0	0.0
0.0	0.0	10.0	23.7	33.7	253.9	350.4	377.7	372.2	330.4	227.5	81.0	16.4	1.8	0.0	0.0
0.0	0.0	9.6	23.0	33.5	247.8	375.1	403.8	395.2	350.2	237.3	75.6	15.3	0.9	0.0	0.0
0.0	0.0	0.0	24.5	36.2	239.1	367.5	408.7	400.8	353.8	243.1	66.7	16.7	1.0	0.0	0.0
0.0	0.0	0.0	24.1	36.1	237.8	355.2	413.4	404.4	347.2	229.8	65.2	15.0	0.0	0.0	0.0
0.0	0.0	0.0	26.2	36.8	214.2	363.3	432.6	422.1	374.9	193.2	62.0	16.8	0.0	0.0	0.0
0.0	0.0	0.0	25.8	40.8	185.7	359.6	429.4	412.2	354.2	234.0	75.1	17.2	0.0	0.0	0.0
0.0	0.0	0.0	53.7	105.3	188.7	352.1	380.6	372.9	260.0	228.1	83.4	16.4	0.0	0.0	0.0
0.0	0.0	0.0	49.1	90.4	202.4	372.7	164.6	176.1	165.8	26.3	36.6	25.1	4.6	0.0	0.0
0.0	0.0	0.0	29.1	35.0	58.4	88.7	199.5	141.2	99.2	101.5	52.5	17.5	5.8	0.0	0.0
0.0	0.0	0.0	35.7	45.2	103.5	415.3	479.6	468.9	414.2	246.3	55.9	16.7	0.0	0.0	0.0
0.0	0.0	0.0	40.8	82.8	168.2	326.5	398.2	389.6	298.1	261.0	61.9	24.8	0.0	0.0	0.0
0.0	0.0	0.0	68.0	118.5	202.9	250.8	291.1	236.9	138.6	157.5	76.8	15.1	3.8	0.0	0.0
0.0	0.0	0.0	24.4	47.5	78.3	95.0	115.5	119.4	61.6	35.9	21.8	11.6	5.1	0.0	0.0
0.0	0.0	0.0	22.6	75.8	99.7	145.0	99.7	139.6	45.2	27.7	16.0	10.7	5.3	0.0	0.0
0.0	0.0	0.0	23.0	59.6	96.1	188.2	334.3	438.5	437.1	215.2	56.8	19.0	0.0	0.0	0.0
0.0	0.0	0.0	41.3	67.4	93.6	345.6	369.0	351.1	301.5	168.0	89.5	33.0	0.0	0.0	0.0
0.0	0.0	0.0	34.2	71.2	153.7	428.5	498.2	314.6	150.9	56.9	39.8	14.2	4.3	0.0	0.0
0.0	0.0	0.0	36.1	94.1	124.4	144.7	270.6	134.5	247.4	128.8	70.9	11.6	0.0	0.0	0.0
0.0	0.0	0.0	35.3	76.4	92.6	188.2	249.9	161.7	117.6	141.1	63.2	23.5	0.0	0.0	0.0
0.0	0.0	0.0	27.3	44.0	66.8	92.5	72.8	65.2	45.5	28.8	18.2	9.1	0.0	0.0	0.0
0.0	0.0	0.0	18.5	29.2	35.4	43.1	47.7	70.8	100.1	106.3	63.2	26.2	0.0	0.0	0.0
0.0	0.0	0.0	34.4	95.3	145.4	233.0	501.9	498.7	414.3	215.7	82.9	20.3	0.0	0.0	0.0
0.0	0.0	0.0	48.3	140.1	207.7	320.4	164.2	161.0	188.4	138.5	66.0	20.9	0.0	0.0	0.0
0.0	0.0	0.0	39.2	83.3	178.1	240.1	379.0	568.5	452.5	202.6	45.7	13.1	0.0	0.0	0.0
0.0	0.0	0.0	26.5	43.1	61.3	270.1	515.2	556.7	475.5	251.8	48.1	14.9	0.0	0.0	0.0
0.0	0.0	0.0	37.4	66.4	76.6	255.5	499.1	337.3	175.5	110.7	57.9	15.3	0.0	0.0	0.0
0.0	0.0	0.0	22.4	46.6	96.7	82.9	91.5	86.4	91.5	120.8	38.0	12.1	0.0	0.0	0.0
0.0	0.0	0.0	42.0	85.7	94.5	98.0	154.1	101.5	73.5	47.3	22.7	12.2	0.0	0.0	0.0
0.0	0.0	0.0	39.5	68.3	107.8	145.5	332.4	150.9	170.7	147.4	82.6	19.8	0.0	0.0	0.0
0.0	0.0	0.0	58.3	121.9	187.5	294.8	334.9	256.6	353.1	258.5	52.8	12.7	0.0	0.0	0.0
0.0	0.0	0.0	22.1	53.5	149.3	206.5	178.9	241.5	173.3	95.8	110.6	22.1	0.0	0.0	0.0
0.0	0.0	0.0	41.6	85.1	86.9	213.6	415.9	321.3	349.7	185.2	77.5	15.1	0.0	0.0	0.0

0.0	0.0	0.0	24.8	49.8	70.8	137.8	522.4	568.3	470.8	264.0	49.8	11.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	62.0	94.9	178.2	457.1	488.1	348.6	195.6	77.4	13.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	55.5	89.2	156.7	521.6	565.3	464.2	257.9	55.5	13.9	0.0	0.0	0.0
0.0	0.0	0.0	0.0	56.2	78.3	134.4	509.7	561.9	471.6	256.9	48.2	10.1	0.0	0.0	0.0
0.0	0.0	0.0	0.0	50.7	73.1	105.5	487.3	550.2	430.4	241.6	50.7	10.2	0.0	0.0	0.0
0.0	0.0	0.0	0.0	70.6	128.8	257.6	367.6	550.4	305.3	155.8	74.8	12.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	33.6	56.7	94.5	107.1	81.9	65.1	37.8	21.0	14.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	65.1	79.8	235.3	277.2	409.5	252.0	105.0	73.5	21.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	29.4	109.2	180.6	92.4	52.5	90.3	50.4	37.8	14.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	73.5	121.8	149.1	147.0	239.4	147.0	90.3	27.3	14.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	67.2	58.8	170.1	199.5	161.7	136.5	119.7	60.9	18.9	0.0	0.0	0.0
0.0	0.0	0.0	0.0	48.3	140.7	270.9	407.4	319.2	359.1	214.2	75.6	18.9	0.0	0.0	0.0
0.0	0.0	0.0	0.0	56.7	86.1	111.3	470.4	468.4	409.5	241.6	63.0	14.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	54.6	79.8	105.0	430.6	420.0	378.0	222.7	58.8	12.6	0.0	0.0	0.0
0.0	0.0	0.0	0.0	58.8	81.9	105.0	382.2	420.0	378.0	214.2	58.8	14.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	84.0	147.0	189.0	357.0	304.6	336.1	224.7	75.6	18.9	0.0	0.0	0.0
0.0	0.0	0.0	0.0	77.7	193.2	222.7	243.6	212.1	117.6	71.4	46.2	16.8	0.0	0.0	0.0
0.0	0.0	0.0	0.0	27.3	58.8	134.4	113.4	144.9	151.2	90.3	23.1	10.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	39.9	73.5	46.2	214.2	378.0	212.1	147.0	69.3	10.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	25.2	153.4	123.9	29.4	75.6	88.2	42.0	21.0	8.4	0.0	0.0	0.0
0.0	0.0	0.0	0.0	46.2	79.8	105.0	136.5	249.9	157.5	96.6	52.5	10.5	0.0	0.0	0.0
0.0	0.0	0.0	0.0	71.4	142.8	229.0	224.7	203.8	170.1	107.1	67.2	14.7	0.0	0.0	0.0
0.0	0.0	0.0	0.0	14.7	25.2	29.4	33.6	31.5	29.4	25.2	16.8	8.4	0.0	0.0	0.0
0.0	0.0	0.0	0.0	115.5	84.0	136.5	241.6	126.0	73.5	52.5	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	94.5	199.5	252.0	315.0	336.1	325.5	220.5	126.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	84.0	136.5	136.5	73.5	73.5	73.5	52.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	73.5	168.0	178.6	189.0	210.1	168.0	147.0	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	84.0	105.0	325.5	336.1	325.5	220.5	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	94.5	157.5	283.5	346.5	231.0	136.5	73.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	52.5	84.0	231.0	325.5	304.6	199.5	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	52.5	73.5	94.5	273.1	367.6	294.0	199.5	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	63.0	84.0	273.1	346.5	273.1	199.5	73.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	63.0	126.0	157.5	147.0	73.5	52.5	42.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	52.5	105.0	210.1	189.0	241.6	136.5	73.5	52.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	63.0	84.0	84.0	73.5	52.5	52.5	31.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	63.0	136.5	199.5	136.5	52.5	10.5	10.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	63.0	136.5	199.5	136.5	52.5	10.5	10.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	10.5	21.0	42.0	63.0	105.0	136.5	126.0	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	63.0	63.0	73.5	42.0	42.0	42.0	31.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	73.5	94.5	94.5	63.0	63.0	42.0	21.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	21.0	52.5	115.5	136.5	157.5	63.0	73.5	73.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	94.5	52.5	52.5	52.5	42.0	73.5	94.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	136.5	189.0	231.0	220.5	178.6	84.0	31.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	126.0	105.0	84.0	84.0	94.5	73.5	10.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	63.0	147.0	189.0	294.0	367.6	283.5	210.1	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	94.5	189.0	189.0	199.5	199.5	105.0	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	105.0	157.5	262.5	220.5	231.0	178.6	84.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	21.0	52.5	73.5	189.0	336.1	336.1	252.0	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	63.0	84.0	210.1	325.5	304.6	273.1	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	42.0	63.0	94.5	231.0	409.5	336.1	262.5	63.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	63.0	84.0	241.6	451.5	388.5	283.5	73.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	31.5	63.0	84.0	252.0	399.1	367.6	252.0	63.0	0.0	0.0	0.0	0.0

APPENDIX XI

OUTPUT OF STATE VARIABLE VALUES FOR THE STANDARD RUN OF THE M & C STREAM MODEL: RIPARIAN VERSION

Appendix XI represents the output generated by the Standard Run of the Riparian Version of the M & C Stream Model (see pages 106-107). In this case, state variables x_2, x_3, x_4, x_5, x_6, x_7, x_{15}, x_{16}, and x_{17} at a time resolution of 30 days were requested by the command file (RIPARIAN.CMD). The Standard Run is produced by the input tables listed in Appendix II and Appendix X and by the parameter values listed in Appendix I, Appendix V, and Appendix IX. This output was printed from an output file (pfile) entitled RIP.OUT.

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Flex5-PC : A Model Processor

Run No.: 1

Target Level: 1
Target title: Riparian Version: Level 1 (daily resolution)


Initial Conditions

B - Parameters    (123)
    -1.000       1.000       0.000       0.000       0.000  1.000E-003
     0.500     268.000    1000.000  2.100E-003    2400.000       0.000
     0.100       0.400       0.000       2.950       0.000       0.000
 2.800E-002      0.583       4.000       0.800       1.000       4.000
     0.500       0.000       0.000       3.500       3.500       0.000
 9.950E-002      0.465       0.895       0.560       1.900       1.510
     0.294       2.030  1.280E-004  1.280E-004  1.380E-003  1.380E-003
    -1.000       0.000       0.187  2.330E-003  1.740E-002       0.000
     0.000       0.300       0.860       0.100  1.870E-003  2.500E-003
 2.600E-002  1.880E-002      0.420       0.820  5.000E-002     100.000
     0.000       0.000       0.000       3.000  1.000E-002  2.800E-002
     0.583  1.000E-003       0.500  1.920E-002  2.100E-003       0.700
     0.000  7.400E-003  1.080E-003       0.100       0.400     268.000
     2.950       0.187  1.460E-002  2.960E-002  1.460E-002      15.000
     0.800      12.000       0.350       0.700       0.237    1000.000
  2400.000       0.550       0.180       0.210       0.000       0.300
     0.300       0.300       0.167       1.000  4.460E-003  4.460E-003
 4.460E-003     -1.000  1.440E-004       0.000  5.850E-002  9.110E-004
 1.990E-004  5.850E-002     -1.000      -1.000      -1.000      -1.000
 3.000E-002  1.750E-002  2.500E-002  -2.83E-002       0.849       1.000
     0.280       1.000       1.000

X - State Variables    (17)
     0.000       0.000       0.000       0.000       0.000       0.110
     1.244       7.626     127.200      25.252      30.851       1.145
    16.978       0.668       1.266       0.000       0.000
```

```
M - Memory    (7)
       0.000        0.000        0.000        0.000        0.000        0.000
       0.000

 Table (2): XNUTR
 Table (3): STRFLOW
 Table (4): SALLOC
 Table (5): FALLOC
 Table (6): GEMER
 Table (7): SEMER
 Table (8): CEMER
 Table (9): PEMER
 Table (10): STRTEMP
 Table (1): LITETAB.RUN


 Print Interval: 30
 Variable Headings
     x[2]         x[3]         x[4]         x[5]         x[6]         x[7]
     x[15]        x[16]        x[17]

 k = 0
       1.056        1.258        2.357        3.708        0.110        1.244
       1.266        0.000        0.000

 k = 30
       1.122        1.905        3.430        3.781        0.198        0.912
       0.927        0.000        0.000

 k = 60
       2.771        2.755        4.497        4.344        0.358        1.174
       1.195        0.000        0.000

 k = 90
       2.479        2.530        4.340        6.414        0.581        0.821
       0.836        0.000        0.000

 k = 120
       2.508        2.256        2.243        9.010        0.840        0.985
       1.003        0.000        0.000

 k = 150
       1.757        0.804        1.387        9.480        1.007        0.933
       0.950        0.000        0.000

 k = 180
       0.659        0.627        1.109        8.216        0.742        0.831
       0.845        0.000        0.000

 k = 210
       0.842        0.539        1.017        6.932        0.464        0.773
       0.786        0.000        0.000

 k = 240
       0.891        0.413        0.976        5.983        0.278        0.849
       0.863        0.000        0.000
```

k = 270					
1.011	0.303	0.869	5.369	0.148	1.101
1.120	0.000	0.000			
k = 300					
1.715	0.421	1.072	4.714	0.102	0.892
0.908	0.000	0.000			
k = 330					
1.394	0.754	1.533	4.134	9.534E-002	0.744
0.757	0.000	0.000			
k = 360					
1.056	1.258	2.358	3.709	0.110	1.245
1.266	0.000	0.000			

APPENDIX XII

ANNUAL ENERGY BUDGET TABLES GENERATED FROM THE STANDARD RUN FOR THE RIPARIAN VERSION OF THE M & C STREAM MODEL

The following tables represent output from BUDGET.COM after STREAM.DMP was introduced as input. In this case, STREAM.DMP was the dump file from the Standard Run of the Riparian Version of the M & C Stream Model (see pages 106-107). The Standard Run is produced by the input tables listed in Appendix II and Appendix X and by the parameter values listed in Appendix I, Appendix V, and Appendix IX. The output listed in Appendix XII is stored in the file STREAM.TAB.

MCINTIRE AND COLBY STREAM MODEL

Energy Budget - Annual Resolution

Simulation Run No. Riparian Version: Standard Run

Table 1. Bioenergetics of the Major Biological Processes

Property	GRAZE	SRED	COLLECT	V-PRED	I-PRED	ALGAE
Biomass (g/m2):						
Mean	1.490	1.217	2.068	6.009	0.410	0.988
Std Dev	0.616	0.859	1.269	1.949	0.303	0.249
Maximum	2.944	2.861	4.767	9.641	1.010	1.952
Minimum	0.647	0.303	0.857	3.662	0.095	0.644
Production (g/m2/yr):						
Gross Primary						79.495
Net Periphyton						68.981
Secondary	5.693	6.209	9.636	5.408	0.872	
Assimilation (g/m2/yr)	41.463	40.958	56.530	15.351	3.645	
Turnover (times/yr)	3.820	5.104	4.659	0.900	2.127	69.784
Energy Losses (g/m2/yr):						
Respiration/post-mortum decomposition	35.770	34.749	46.894	9.943	2.773	10.515
To invert. predation	1.446	1.148	1.851			
To vert. predation	3.038	2.754	4.449		0.619	
To grazing						56.262
Emergence	1.230	2.326	3.370		0.254	
Vert. mortality				5.399		
Periphyton export:						
Large particle						3.052
Fine particle						8.302
DOM leakage						1.408
Energy Losses (% of assimilation):						
Respiration/post-mortum decompostion	86.27%	84.84%	82.95%	64.77%	76.08%	13.23%
To invert. predation	3.49%	2.80%	3.27%			
To vert. predation	7.33%	6.72%	7.87%		16.98%	
To grazing						70.77%
Emergence	2.97%	5.68%	5.96%		6.97%	
Vert. mortality				35.17%		
Periphyton export:						
Large particle						3.84%
Fine particle						10.44%
DOM leakage						1.77%

Table 2. Bioenergetics of Detrital Processes

Property	FPOM	Total LPOM	Conditioned SLPOM	Conditioned FLPOM	Unconditioned SLPOM	Unconditioned FLPOM
Biomass (g/m2):						
Mean	10.584	91.715	52.399	9.887	28.847	1.096
Std Dev	6.215	57.125	41.619	8.561	14.046	0.691
Maximum	26.310	187.605	128.049	25.252	63.912	3.509
Minimum	3.736	0.000	0.487	0.119	15.312	0.389
Inputs (g/m2/yr):						
Terrestrial SLPOM		401.057				
Terrestrial FLPOM		71.829				
Aquatic (feces):						
Primary consumption	414.048					
Predation	3.299					
Mechanical from LPOM	53.928					
Energy Losses (g/m2/yr):						
Microbial decomposition	121.844	116.116				
To collecting	269.192					
To shredding		227.544				
Export	80.496	75.060				
Mechanical to FPOM		53.928				
Energy Losses (% of total inputs):						
Microbial decomposition	25.85%	24.55%				
To collecting	57.12%					
To shredding		48.12%				
Export	17.08%	15.87%				
Mechanical to FPOM		11.40%				

Table 3. Ecosystem Energy Budget (g/m2/yr)

Property	Inputs		Outputs
Gross Primary Production (GPP)	79.495		
Allochthonous Materials:			
SLPOM	401.057		
FLPOM	71.829		
Drift from Upstream	6.990		
Community Respiration (CR)			378.603
Insect Emergence			7.181
Export/Natural Mortality			173.716
Total	559.371		559.500
Net Gain or Loss		-0.129	
GPP/CR		0.210	