

#### 4.8 Mortality and re-growth of terrestrial vegetation (VEGMOD)

PROCESSES: VBMORT(I), VB(I)\_MRT3W, VB(I)\_MRT3S, VBGROWTH(I), VB(I)UPT, VB(I)\_UPT3D, VB(I)AVAILN, VBSTATUS(I)

The vegetation sub-model simulates the effects of the drowning and re-growth of vegetation in water systems such as (man-made) reservoirs on water quality. The design of the module is generic to allow for a comprehensive processes content, but only the most essential formulations for growth and mortality have been included. Starting from a standing stock of biomasses for a number of vegetation cohorts (types, species, etc.), mortality due to inundation leads to the allocation of organic matter (C, N, P, S) to the POX1–3 and POX5 fractions in water and sediment. Re-growth in areas ran dry may lead to the building up of a standing stock of new vegetation biomass, the nutrients for which are withdrawn from the sediment.

A cohort is treated as a homogeneous entity in the model in terms of variables (state variable, coefficients and mass fluxes). The number of vegetation cohorts in the model is limited to a maximum 9. Various cohorts may be present in the same model grid cell. The total biomasses of the cohorts are modelled as inactive substances expressed in grams carbon per m<sup>2</sup>. These not transported state variables only exist in the lower water layer. Additional output parameters provide total biomass for each cohort expressed in tonnes C per ha. The concurrent organic nutrients (nitrogen, phosphorus, sulphur) in vegetation biomass are not modelled as state variables, but as quantities derived from the carbon state variables using stoichiometric ratio's.

Each cohort of vegetation consists of the following above-ground and below-ground compartments: 1) stems, 2) foliage, 3) branches, 4) roots, 5) fine roots. The fractions of biomass of these compartments for each vegetation cohort imposed as allocation factors are used to calculate the fluxes of biomass turned over into the various detritus pools in the layers of the water column and the sediment (Figure 4.6). Nutrients are stored in the compartments in agreement with compartment specific stoichiometric constants.

Mortality starts after a lag time following inundation and proceeds according to a first-order decay of living biomass. Foliage and fine roots are allocated to the detritus pools in the water and sediment layers according to vegetation height and rooting depth.

Growth is calculated from a predefined growth curve, and will stop once a certain target biomass is achieved (Figure 4.7). Growth may be limited by the quantities of nutrients available in the sediment according to rooting depth. Nitrogen is taken from ammonium (NH<sub>4</sub>, preferred) and nitrate (NO<sub>3</sub>), phosphorus from dissolved and adsorbed phosphate (PO<sub>4</sub>, preferred, and AAP), and sulphur from sulphate (SO<sub>4</sub>, preferred) and dissolved sulphide (SUD). Carbon is taken up from the atmosphere. For each vegetation cohort (re-)growth may be prevented or allowed by means of two "option" parameters. In this way it can be manipulated that initially present types do not (re-)grow.

##### Implementation

The processes of vegetation module VEGMOD have been implemented for the following substances:

- ◇ VB01, VB02, VB03, VB04, VB05, VB06, VB07, VB08, VB09
- ◇ POC1, PON1, POP1, POS1, POC2, PON2, POP2, POS2, POC3, PON3, POP3, POS3, POC5, PON5, POP5, POS5

◇ NH<sub>4</sub>, NO<sub>3</sub>, PO<sub>4</sub>, AAP, SO<sub>4</sub>, SUD

Processes VBMORT(i) calculate the mortality rates and the detritus release rates. Processes VB(i)\_MRT3W and VB(i)\_MRT3S distribute the release rates among water and sediment layers. Processes VBGROWTH(i) calculates the growth rates as based on available nutrients in the sediment. Processes VB(i)AVAILN determine the available quantities of the nutrients (N, P, S), whereas processes VB(i)UPT and VB(i)\_UPT3D calculate the nutrient uptake rates for the sediment layers. Processes VBSTATUS(i) keep record of the inundation time, and set the option parameters for growth and mortality (*SWVB(i)Gro* and *SWVB(i)Mrt*). (i) is the number of a vegetation cohort (01–09).

Table 4.11 provides the definitions of the input parameters occurring in the formulations, and Table 4.12 provides the output parameters.

## Formulation

### (Re-)Growth

The growth curve of a vegetation cohort is defined by 4 parameters; minimum biomass, maximum target biomass, cohort age where 50 % of maximum biomass is achieved and a factor for the shape of the growth curve (Figure 4.7). The “target” attainable biomass is thus a function of the age of the vegetation cohort. The actual biomass growth in each time step of the simulation is determined from the “target” attainable biomass for the current age and the actual biomass. The calculation of growth starts with determination of the total attainable biomass of each vegetation cohort as resulting from the growth curve:

$$Mveg_{a,i} = \frac{(Mveg_{min,i} - Mveg_{max,i})}{1 + \exp(sf_i \times (ag_i - ag_{hb,i})/ag_{hb,i})} + Mveg_{max,i}$$

where:

<i>ag</i>	age of vegetation [d]
<i>ag<sub>hb</sub></i>	age of vegetation when half of attainable biomass is reached [d]
<i>Mveg<sub>a</sub></i>	attainable biomass in all compartments [gC.m <sup>-2</sup> ]
<i>Mveg<sub>max</sub></i>	maximum biomass in all compartments [gC.m <sup>-2</sup> ]
<i>Mveg<sub>min</sub></i>	minimum biomass in all compartments [gC.m <sup>-2</sup> ]
<i>sf</i>	shape factor of the growth function [-]
<i>i</i>	index for vegetation cohorts (1–9)

The initial vegetation biomass at the start of the simulation ( $t = 0$ ) is computed from the amount of vegetation biomass dry matter per ha. Optionally, a percentage of surface coverage may be used in the calculation of initial biomass according to:

$$Mveg_i = fa_i \times Mveg_0 / dmc_i$$

where:

<i>dmc</i>	dry matter carbon ratio [gDM.gC <sup>-1</sup> ]
<i>fa</i>	percentage of area coverage [%]
<i>Mveg</i>	actual biomass in all compartments [gC.m <sup>-2</sup> ]
<i>Mveg<sub>0</sub></i>	initial biomass in all compartments [tDM.ha <sup>-1</sup> ]

If growth takes place ( $SWVB(i)Gro = 1.0$ ), the potential (or target) growth rate of biomass per vegetation cohort results from:

$$Rgr_{p,i} = (Mveg_{a,i} - Mveg_i) / \Delta t$$

where:

$Rgr_p$	potential growth rate of biomass in all compartments [gC.m <sup>-2</sup> .d <sup>-1</sup> ]
$\Delta t$	computational time step [d]

In a final step the growth is corrected for nutrient limitation. In case of nutrient limitation, the above potential growth rates  $Rgr_{p,i}$  are reduced to actual growth rates  $Rgr_i$  in proportion with the available quantity of the growth limiting nutrient. These actual growth rates are calculated from the potential growth rates multiplied with the ratio of the available quantity of the most limiting nutrient and the quantity of this nutrient needed to sustain the potential growth rates ( $NutLimVB(i)$ ).

When inundation occurs, the vegetation stops growing ( $SWVB(i)Gro = 0.0$ ), and the vegetation age remains constant at the current age until inundation is over. When vegetation growth is limited by a shortage of nutrients, vegetation growth and age are reduced accordingly. Initial age is calculated from the initial biomass using the formulation of the growth curve. Age is reset to zero if the vegetation dies (see below).

#### Uptake of nutrients

Nutrients (N, P and S) are taken up by vegetation from the sediment within rooting depth, whereas carbon is taken up from the atmosphere. The total uptake rates are computed using vegetation cohort and biomass compartment specific carbon to nutrient ratios. The total uptake rates are distributed among the sediment layers within rooting depth proportional to the quantities of the nutrients available in the layers (grid cells). The nutrient uptake rates result from:

$$Rup_{ln} = fn_{ln} \times Rgr_i \times \sum_{j=1}^5 (fb_{ij} / vn_{lij}) / H$$

$$Rup_{t,l} = \sum_{i=1}^9 \left( \sum_{n=1}^{nr} (Rup_{iln}) \right)$$

where:

$fb$	fraction of biomass in a compartment [-]
$fn$	fraction of total available nutrient in a layer [-]
$H$	sediment layer thickness [-]
$Rgr$	growth rate of biomass in all compartments [gC.m <sup>-2</sup> .d <sup>-1</sup> ]
$Rup$	uptake rate of nutrients in all compartments [gN/P/S.m <sup>-3</sup> .d <sup>-1</sup> ]
$Rupt$	total uptake rate of nutrients in all compartments [gN/P/S.m <sup>-3</sup> .d <sup>-1</sup> ]
$vn$	carbon nutrient ratio in vegetation biomass [gC.gN/P/S <sup>-1</sup> ]
$l$	index for nutrient (1=nitrogen, 2=phosphorus, 3=sulphur)
$i$	index for vegetation cohorts (1–9)
$j$	index for biomass compartments (1=stem, 2=foliage, 3=branches, 4=roots, 5=fine roots)
$n$	index for a sediment layer (nr = number of layer within rooting depth)

The quantities of available nutrients are derived the nutrient concentrations ( $C_{am}$ ,  $C_{ni}$ ,  $C_{ph}$ ,  $C_{ap}$ ,  $C_{su}$ ,  $C_{sud}$ ) in the sediment layers within rooting depth. When not enough nutrient is available to sustain potential growth, the growth rates have been reduced proportionally (see above). In order to avoid numerical errors when all available nutrient would be depleted the maximum fraction of the available nutrients that can be taken up in a time step can be made smaller than 1.0 by means of input parameter  $VBFrMaxU$ .

#### Mortality and detritus release

The onset of mortality from the start of the simulation can be imposed optionally, using option parameter  $IniVB(i)Dec=1.0$ . If the duration of inundation exceeds a lag time defined as the critical number of subsequent days with inundation, the vegetation cohorts in the inundated area will start to die:

$$\text{if } SwEmersion = 0.0 \text{ then } ti = ti + \Delta t \text{ else } ti = 0.0$$

$$\text{if } ti > ti_{c,i} \text{ then } ag_i = 0.0 \text{ and } SwVB_iMrt = 0.0$$

where:

$ag$	age of biomass [d]
$ti$	inundation period, the number of successive days of inundation [d]
$ti_c$	critical inundation period, the mortality lag time [d]
$SwEmersion$	switch for inundation (0 = yes, 1 = no)
$SwVB_iMrt$	switch for mortality (0 = yes, 1 = no)
$\Delta t$	computational time step [d]
$i$	index for vegetation cohorts (1–9)

The lag time for mortality due to inundation is input to the model and not a function of local conditions such as the dissolved oxygen concentration. The duration of inundation prior to the simulation start time  $ti_0$  can be imposed.

Mortality results in the decrease of vegetation biomass and the transfer of vegetation biomass to the particulate detritus fractions. Detritus from foliage, stems and branches goes to water layers, detritus from fine roots and roots to sediment layers. The detritus release rates for each sediment grid cell are computed using vegetation cohort and biomass compartment specific carbon to nutrient ratios and the fraction of biomass allocated to a water or sediment layer. This fraction is derived from vegetation height and rooting depth and the fractions of biomass allocated to each of the five biomass compartments (see below). The mortality rate of the vegetation biomass and the release rates of organic nutrients follow from:

$$Rmrt_i = kmrt_i \times Mveg_i$$

$$Rmrd_{klij} = fh_i \times fd_{kij} \times fb_{ij} \times Rmrt_i / (vn_{lij} \times H)$$

where:

$fb$	fraction of biomass in a compartment [-]
$fd$	fraction of biomass released into a specific detritus fraction [-]
$fh$	fraction of biomass in a layer [-]
$H$	water layer or sediment layer thickness [-]
$kmrt$	mortality rate constant [ $d^{-1}$ ]
$Mveg$	actual biomass in all compartments [ $gC.m^{-2}$ ]

$Rmrd$	release rate of detritus [gC/N/P/S.m <sup>-3</sup> .d <sup>-1</sup> ]
$Rmrt$	mortality rate of biomass [gC.m <sup>-2</sup> .d <sup>-1</sup> ]
$vn$	carbon nutrient ratio in vegetation biomass [gC.gC/N/P/S <sup>-1</sup> ]
$k$	index for detritus fraction (1 = POX1, 2 = POX2, 3 = POX3, 5 = POX5)
$l$	index for carbon and nutrient (0 = carbon, 1 = nitrogen, 2 = phosphorus, 3 = sulphur)
$i$	index for vegetation cohorts (1–9)
$j$	index for biomass compartments (1 = stem, 2 = foliage, 3 = branches, 4 = roots, 5 = fine roots)

The fractions  $fd$  for foliage and fine roots to POX1–3 are derived from input parameters. The fractions  $fd$  for stems, branches and large roots to POX5 are equal to 1.0.

#### Vertical distribution of the detritus release rates

In order to obtain vertical distributions of the detritus release rates, the biomass compartments of each vegetation cohort are distributed virtually among the layers (grid cells) in each water-sediment column. A distinction is made between the compartments in above-ground biomass (foliage, branches, stems) and the compartments in below-ground biomass (roots, fine roots). Above-ground biomass of each cohort has a vegetation height. Below-ground biomass of each cohort has a rooting depth. Based on these parameters, the number of water layers and sediment layers involved in the distribution are determined. Water layers above vegetation height and sediment layers below rooting depth have zero biomass, and therefore zero detritus release.

The distribution is determined from the total above-ground or the total below-ground biomass per m<sup>2</sup> using a distribution shape constant. The total above-ground and total below-ground biomass is derived from the total biomass of a vegetation cohort and the biomass fractions in the five compartments. The shape constant is given by:

$$Fs_i = \frac{Cveg_i(z_{max,i})}{(Mveg_{p,i}/H_{max,i})}$$

where:

$Fs$	shape constant for vertical distribution of biomass [-]
$Cveg(z_{max})$	above-ground or under-ground biomass at $z_{max}$ [gC.m <sup>-3</sup> ]
$Mveg_p$	above-ground or under-ground biomass [gC.m <sup>-2</sup> ]
$H_{max}$	vegetation height (positive) or rooting depth (negative) [m]
$z_{max}$	water depth (positive) at vegetation height or sediment (negative) depth at rooting depth [m]
$i$	index for vegetation cohorts (1–9)

The value of shape constant  $Fs$  varies from 0 to 2. When  $Fs = 0$  the biomass  $Cveg$  is zero at  $z_{max}$ , when  $Fs = 1$  biomass  $Cveg$  is homogeneously distributed (constant over depth), and when  $Fs = 2$  biomass  $Cveg$  is zero at the sediment. For values of  $Fs$  between 0 and 1 biomass decreases towards vegetation height or rooting depth. For  $Fs$ -values between 1 and 2 the biomass decreases towards the sediment. The effects of  $F$  on the distribution appear from [Figure 4.8](#).

A linear distribution function is formulated using two constants,  $a$  and  $b$ . Both are fixed when  $F$  is fixed because the integral of the biomass distribution must equal the total biomass. The

vertical distribution within the water column or the sediment column follows from:

$$Cveg_i(z) = a_i \times z + b_i$$

$$a_i = \frac{Mveg_{p,i}}{H_{max,i}} \times \frac{(2 - 2 \times Fs_i)}{(H_t - z_{max,i})}$$

$$b_i = \frac{Mveg_{p,i}}{H_{max,i}} \times \frac{(Fs_i \times (z_{max,i} + H_t) - 2 \times z_{max,i})}{(H_t - z_{max,i})}$$

The biomass fraction  $fh_i$  in a layer n between  $z_n$  and  $z_{n+1}$  follows from:

$$\int_{z_n}^{z_{n+1}} (Cveg_i(z)/Mveg_i) dz = \frac{A}{2} (z_{n+1}^2 - z_n^2) + B (z_{n+1} - z_n)$$

$$fh_i = \begin{cases} \int_{z_n}^{z_{n+1}} (Cveg_i(z)/Mveg_i) dz & \text{if } z_n > z_{max,i} \\ \int_{z_n}^{z_{max,i}} (Cveg_i(z)/Mveg_i) dz & \text{if } z_n \leq z_{max,i} \end{cases}$$

with:

$$\int_{z_n}^{z_{n+1}} (Cveg_i(z)/Mveg_i) dz = \frac{A}{2} (z_{n+1}^2 - z_n^2) + B (z_{n+1} - z_n)$$

where:

$Cveg(z)$	above-ground or under-ground biomass at water or sediment depth $z$ [gC.m <sup>-3</sup> ]
$fh$	fraction of biomass in a water or sediment layer [-]
$H_t$	total water depth or total sediment depth [m]
$Mveg$	biomass in all compartments [gC.m <sup>-2</sup> ]
$Mveg_p$	above-ground or under-ground biomass [gC.m <sup>-2</sup> ]
$z$	water depth (positive) or sediment depth (negative) at bottom of a layer [m]
$i$	index for vegetation cohorts (1–9)

For  $Fs = 1$  the integral reduces to:

$$fh_i = \frac{Mveg_{p,i}}{Mveg_i} \times \frac{(z_{n+1} - z_n)}{H_{max,i}} \quad \text{if } z_n > z_{max,i}$$

$$fh_i = \frac{Mveg_{p,i}}{Mveg_i} \times \frac{(z_{max,i} - z_n)}{H_{max,i}} \quad \text{if } z_n < z_{max,i} \text{ and } z_{n+1} > z_{max,i}$$

### Directives for use

- 1 Two options are available for the input of initial vegetation biomasses. For  $SwIniVB(i)=1.0$  the model expects percentual coverage and initial biomass in tDM.ha<sup>-1</sup> for each vegetation type. For  $SwIniVB(i)=0.0$  the model expects biomasses in tDM.ha<sup>-1</sup> for each vegetation type for each grid cell.
- 2 The input for initial biomasses may be generated as a GIS map representing each model grid cell, for instance based on a satellite image.
- 3 The option for the vertical distribution of biomass and detritus fluxes  $SWDisVB(i)$  overlaps the distribution shape factor  $FfacVB(i)$ . If  $FfacVB(i)=1.0$   $SWDisVB(i)$  must equal 1.0 as well. The linear and exponential distributions ( $SWDisVB(i)=2.0$  or  $3.0$ ) are not fully implemented.

- 4 The option parameter  $IniVB(i)Dec$  can be used to impose mortality from the start of the simulation. Default value 0.0 implies “no” mortality, value 1.0 causes mortality from the start.
- 5 The maximum fraction of the available nutrients that can be taken up in a time step  $VBFr-MaxU$  ( $<1.0$ ) has a default value of 0.5. To avoid too strong nutrient limitation its value can be increased, but one should verify that this does not cause numerical errors.

**Table 4.11:** Definitions of the input parameters in the above equations for  $VBMORT(i)$ ,  $VB(i)MRT3W$ ,  $VB(i)MRT3S$ ,  $VBGROWTH(i)$ ,  $VB(i)UPT$ ,  $VB(i)UPT3D$ ,  $VB(i)AVAILN$  and  $VBSTATUS(i)$ .

Name in formulas <sup>1</sup>	Name in input <sup>1</sup>	Definition	Units
$ag_{hb, i}$	$HlfAgeVb(i)$	age of veg. when half of attainable biomass is reached	d
$Cam$	$NH4$	concentration of ammonium	$gN.m^{-3}$
$Cni$	$NO3$	concentration of nitrate	$gN.m^{-3}$
$Cph$	$PO4$	concentration of dissolved phosphate	$gP.m^{-3}$
$Cap$	$AAP$	concentration of adsorbed phosphate	$gP.m^{-3}$
$Csu$	$SO4$	concentration of sulphate	$gS.m^{-3}$
$Csud$	$SUD$	concentration of dissolved sulphide	$gS.m^{-3}$
$dmc_i$	$DMcfVB(i)$	dry matter carbon ratio	$gDM.gC^{-1}$
$fa_i$	$IniCovVB(i)$	percentage of area coverage	%
$fb_{i,j}$	$F1VB(i)$	fraction of biomass in compartment 1 (stems)	-
	$F2VB(i)$	fraction of biomass in comp. 2 (foliage)	-
	$F3VB(i)$	fraction of biomass in comp. 3 (branches)	-
	$F4VB(i)$	fraction of biomass in comp. 4 (roots)	-
	$F5VB(i)$	fraction of biomass in comp. 5 (fine roots)	-
$fd_{1;2}$	$FfolPOC1$	biomass fraction 2 (foliage) to detr. POX1	-
$fd_{2;2}$	$FfolPOC2$	biomass fraction 2 (foliage) to detr. POX2	-
$fd_{1;5}$	$FfrootPOC1$	biomass fraction 2 (fine roots) to detr. POX1	-
$fd_{2;5}$	$FfrootPOC2$	biomass fraction 2 (fine roots) to detr. POX2	-
$Fs$	$FfacVB(i)$	shape constant for vertical distr. of biomass	-
$H$	$Depth$	water layer or sediment layer thickness	m
$H_{max}$	$VegHeVB(i)$	vegetation height (positive)	m
$H_{max}$	$RootDeVB(i)$	rooting depth (negative)	m
$H_t$	$TotalDepth$	total water depth or total sediment depth	m
$z$	$LocalDepth$	depth to the bottom of a water layer	m
$z$	$LocSedDept$	depth to the bottom of a sediment layer	m
-	$Surf$	surface area of a grid cell	$m^{-2}$
-	$Volume$	volume of a grid cell	$m^{-3}$
$kmrt_i$	$RcMrtVB(i)$	mortality rate constant	$d^{-1}$
$Mveg$	$VB(i)$	vegetation biomass in all five compartments	$gC.m^{-2}$
$Mveg_0$	$IniVB(i)$	initial biomass in all five compartments	$tDM.ha^{-1}$



Name in formulas <sup>1</sup>	Name in input <sup>1</sup>	Definition	Units
$Mveg_{max,i}$ $Mveg_{min,i}$	$MaxVB(i)$ $MinVB(i)$	maximum biomass in all five compartments minimum biomass in all five compartments	$gC.m^{-2}$ $gC.m^{-2}$
$sf_i$	$SfVB(i)$	shape factor of the growth function	-
$SWEmersion$ $SWDisVB(i)$ $SwIniVB(i)$ $IniVB(i)Dec$ $SwRegrVB(i)$	$SWEmersion$ $SWDisVB(i)$ $SwIniVB(i)$ $IniVB(i)Dec$ $SwRegrVB(i)$	switch for inundation (0 = yes, 1 = no) option vert. distr. (1=const., 2=linear, 3=exp.) option init. biomass (0=biomass, 1=coverage) option mort. at start of simul. (0=no, 1=yes) option for re-growth (0=no, 1=yes)	- - - - -
$VBFrMaxU$	$VBFrMaxU$	max. fr. of nutrients taken up in a time step	-
$vn_{1ij}$      $vn_{2ij}$       $vn_{3ij}$	$CNF1VB(i)$ $CNF2VB(i)$ $CNF3VB(i)$ $CNF4VB(i)$ $CNF5VB(i)$ $CPF1VB(i)$ $CPF2VB(i)$ $CPF3VB(i)$ $CPF4VB(i)$ $CPF5VB(i)$ $CSF1VB(i)$ $CSF2VB(i)$ $CSF3VB(i)$ $CSF4VB(i)$ $CSF5VB(i)$	carbon nitrogen ratio in comp. 1 (stems) carbon nitrogen ratio in comp. 2 (foliage) carbon nitrogen ratio in comp. 3 (branches) carbon nitrogen ratio in comp. 4 (roots) carbon nitrogen ratio in comp. 5 (fine roots) carbon phosphorus ratio in comp. 1 (stems) carbon phosphorus ratio in comp. 2 (foliage) carbon phos. ratio in comp. 3 (branches) carbon phosphorus ratio in comp. 4 (roots) carbon phos. ratio in comp. 5 (fine roots) carbon sulphur ratio in comp. 1 (stems) carbon sulphur ratio in comp. 2 (foliage) carbon sulphur ratio in comp. 3 (branches) carbon sulphur ratio in comp. 4 (roots) carbon sulphur ratio in comp. 5 (fine roots)	$gC.gN^{-1}$ $gC.gN^{-1}$ $gC.gN^{-1}$ $gC.gN^{-1}$ $gC.gN^{-1}$ $gC.gP^{-1}$ $gC.gP^{-1}$ $gC.gP^{-1}$ $gC.gP^{-1}$ $gC.gP^{-1}$ $gC.gS^{-1}$ $gC.gS^{-1}$ $gC.gS^{-1}$ $gC.gS^{-1}$ $gC.gS^{-1}$
$ti_{c,i}$ $ti_{0,i}$	$CrnsfVB(i)$ $Initnsfd$	critical inundation period, mortality lag time inundation period prior to sim. start time	d d
$\Delta t$	$Delt$	computational time step	d

<sup>1)</sup>  $i=1-9$  or  $(i)=01-09$  is the vegetation cohort number;  $j=1-5$  is the biomass compartment number.

**Table 4.12:** Definitions of the additional output parameters for  $VBMORT(i)$ ,  $VB(i)_{MRT3W}$ ,  $VB(i)_{MRT3S}$ ,  $VBGROWTH(i)$ ,  $VB(i)_{UPT}$ ,  $VB(i)_{UPT3D}$ ,  $VB(i)_{AVAILN}$  and  $VBSTATUS(i)$ .

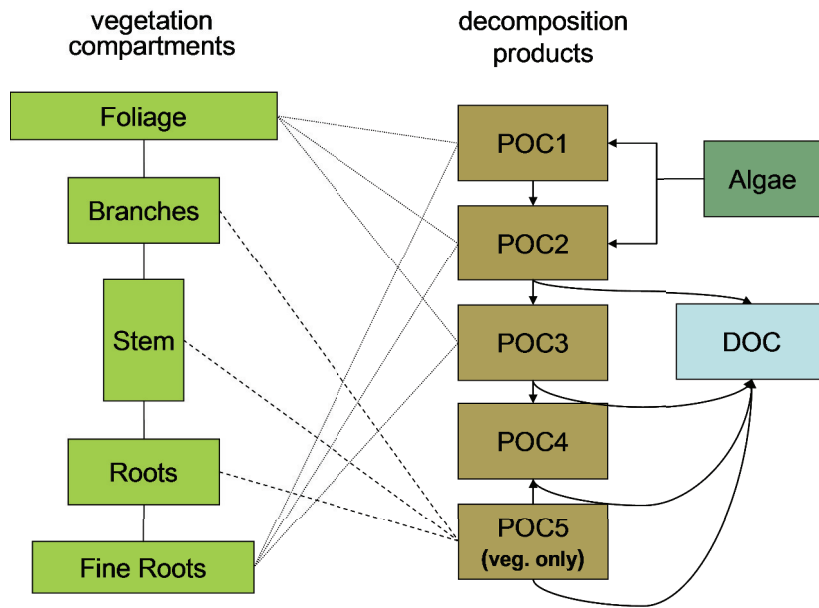
Name in formulas <sup>1</sup>	Name in output <sup>1</sup>	Definition <sup>2</sup>	Units
$ti_i$	$AgeVB(i)$	age of vegetation biomass	d
-	$fNVB(i)UP$ $fPVB(i)UP$ $fSVB(i)UP$	N vegetation uptake flux P vegetation uptake flux S vegetation uptake flux	$gN.m^{-2}.d^{-1}$ $gP.m^{-2}.d^{-1}$ $gS.m^{-2}.d^{-1}$



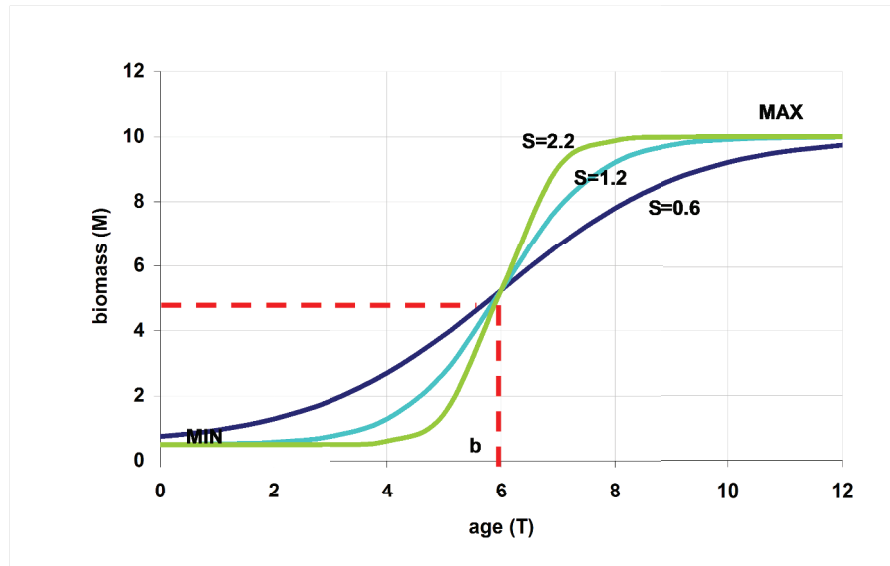
Name in formulas <sup>1</sup>	Name in output <sup>1</sup>	Definition <sup>2</sup>	Units
	<i>fN1VB(i)UPy</i> <i>fN2VB(i)UPy</i> <i>fP1VB(i)UPy</i> <i>fP2VB(i)UPy</i> <i>fS1VB(i)UPy</i> <i>fS2VB(i)UPy</i>	ammonium N vegetation uptake flux nitrate N vegetation uptake flux dissolved phosphate P vegetation uptake flux adsorbed phosphate P vegetation uptake flux sulphate S vegetation uptake flux dissolved sulphide S vegetation uptake flux	$\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$
-	<i>fC1VB(i)P5</i> <i>fN1VB(i)P5</i> <i>fP1VB(i)P5</i> <i>fS1VB(i)P5</i> <i>fC2VB(i)P1</i> <i>fN2VB(i)P1</i> <i>fP2VB(i)P1</i> <i>fS2VB(i)P1</i> <i>fC2VB(i)P2</i> <i>fN2VB(i)P2</i> <i>fP2VB(i)P2</i> <i>fS2VB(i)P2</i> <i>fC2VB(i)P3</i> <i>fN2VB(i)P3</i> <i>fP2VB(i)P3</i> <i>fS2VB(i)P3</i> <i>fC3VB(i)P5</i> <i>fN3VB(i)P5</i> <i>fP3VB(i)P5</i> <i>fS3VB(i)P5</i> <i>fC4VB(i)P5</i> <i>fN4VB(i)P5</i> <i>fP4VB(i)P5</i> <i>fS4VB(i)P5</i> <i>fC5VB(i)P1</i> <i>fN5VB(i)P1</i> <i>fP5VB(i)P1</i> <i>fS5VB(i)P1</i> <i>fC5VB(i)P2</i> <i>fN5VB(i)P2</i> <i>fP5VB(i)P2</i> <i>fS5VB(i)P2</i> <i>fC5VB(i)P3</i> <i>fN5VB(i)P3</i> <i>fP5VB(i)P3</i> <i>fS5VB(i)P3</i>	C flux from biomass comp. 1 to detritus POC5 N flux from biomass comp. 1 to detritus POC5 P flux from biomass comp. 1 to detritus POC5 S flux from biomass comp. 1 to detritus POC5 C flux from biomass comp. 2 to detritus POC1 N flux from biomass comp. 2 to detritus POC1 P flux from biomass comp. 2 to detritus POC1 S flux from biomass comp. 2 to detritus POC1 C flux from biomass comp. 2 to detritus POC2 N flux from biomass comp. 2 to detritus POC2 P flux from biomass comp. 2 to detritus POC2 S flux from biomass comp. 2 to detritus POC2 C flux from biomass comp. 2 to detritus POC3 N flux from biomass comp. 2 to detritus POC3 P flux from biomass comp. 2 to detritus POC3 S flux from biomass comp. 2 to detritus POC3 C flux from biomass comp. 3 to detritus POC5 N flux from biomass comp. 3 to detritus POC5 P flux from biomass comp. 3 to detritus POC5 S flux from biomass comp. 3 to detritus POC5 C flux from biomass comp. 4 to detritus POC5 N flux from biomass comp. 4 to detritus POC5 P flux from biomass comp. 4 to detritus POC5 S flux from biomass comp. 4 to detritus POC5 C flux from biomass comp. 5 to detritus POC1 N flux from biomass comp. 5 to detritus POC1 P flux from biomass comp. 5 to detritus POC1 S flux from biomass comp. 5 to detritus POC1 C flux from biomass comp. 5 to detritus POC2 N flux from biomass comp. 5 to detritus POC2 P flux from biomass comp. 5 to detritus POC2 S flux from biomass comp. 5 to detritus POC2 C flux from biomass comp. 5 to detritus POC3 N flux from biomass comp. 5 to detritus POC3 P flux from biomass comp. 5 to detritus POC3 S flux from biomass comp. 5 to detritus POC3	$\text{gC.m}^{-3}.\text{d}^{-1}$ $\text{gN.m}^{-3}.\text{d}^{-1}$ $\text{gP.m}^{-3}.\text{d}^{-1}$ $\text{gS.m}^{-3}.\text{d}^{-1}$ $\text{gC.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$ $\text{gC.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$ $\text{gC.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$ $\text{gC.m}^{-3}.\text{d}^{-1}$ $\text{gN.m}^{-3}.\text{d}^{-1}$ $\text{gP.m}^{-3}.\text{d}^{-1}$ $\text{gS.m}^{-3}.\text{d}^{-1}$ $\text{gC.m}^{-3}.\text{d}^{-1}$ $\text{gN.m}^{-3}.\text{d}^{-1}$ $\text{gP.m}^{-3}.\text{d}^{-1}$ $\text{gS.m}^{-3}.\text{d}^{-1}$ $\text{gC.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$ $\text{gC.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$ $\text{gC.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$ $\text{gC.m}^{-2}.\text{d}^{-1}$ $\text{gN.m}^{-2}.\text{d}^{-1}$ $\text{gP.m}^{-2}.\text{d}^{-1}$ $\text{gS.m}^{-2}.\text{d}^{-1}$
<i>Rgr<sub>i</sub></i>	<i>fVB(i)</i>	actual vegetation biomass growth rate	$\text{gC.m}^{-2}.\text{d}^{-1}$
<i>NutLimVB(i)</i>	<i>NutLimVB(i)</i>	nutrient limitation factor for growth ( $\leq 1.0$ )	-

Name in formulas <sup>1</sup>	Name in output <sup>1</sup>	Definition <sup>2</sup>	Units
-	$VB(i)ha$ $VB(i)Aha$	vegetation biomass density attainable vegetation biomass density	$tC.ha^{-1}$ $tC.ha^{-1}$
-	$VB(i)Navail$ $VB(i)Pavail$ $VB(i)Savail$	available nutrient N within rooting depth available nutrient P within rooting depth available nutrient S within rooting depth	$gN.m^{-2}$ $gP.m^{-2}$ $gS.m^{-2}$
- SWVB(i)Gro SWVB(i)Mrt	$SWVB(i)Dec$ $SWVB(i)Gro$ $SWVB(i)Mrt$	switch continuation mortality (0 = no, 1 = yes) switch for growth (0 = no, 1 = yes) switch for mortality (0 = no, 1 = yes)	- - -

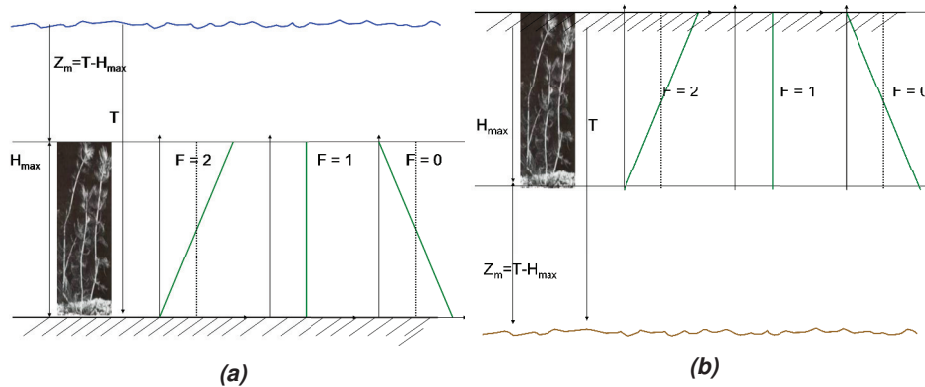
- <sup>1)</sup>  $(i)=01-09$  is the vegetation cohort number;  $j=1-5$  is the biomass compartment number.  
<sup>2)</sup> Vegetation biomass compartments are 1=stems, 2=foliage, 3=branches, 4=roots and 5=fine roots.



**Figure 4.6:** Interactions between the compartments of a vegetation cohort (left side, green) and the detritus fractions POC1–5/DOC in the model (particulate fractions brown, dissolved fraction blue). Similar schemes apply to PON1–5/DON, POP1–5/DOP and POS1–5/DOS.



**Figure 4.7:** The growth curve of a vegetation cohort ( $y$ -axis) as a function of its age is a function of 4-parameters: minimum biomass (MIN), maximum target biomass (MAX), cohort age where 50 % of maximum biomass is achieved ( $b$ ) and a factor indicating how ‘smooth’ the growth curve is ( $s$ ).



**Figure 4.8:** The effect of shape constant  $F_s(F)$  on the distribution of vegetation biomass above the sediment (a) and vegetation biomass in the sediment (b). The symbols used are explained in the text ( $T = H_t$ ).