Appendix B: Meaning of the acronyms, functional group codes and symbols used.

Table B.1: List of the acronyms commonly used in this thesis

Acronym	Meaning
BM2	Bay Model 2
CM	Model runs with nutrient loadings scaled to match the loadings of Chesapeake Bay
IGBEM	Integrated Generic Bay Ecosystem Model
PPB	Port Phillip Bay (near Melbourne, Australia)
PPBIM	Port Phillip Bay Integrated Model
PM	Model runs with nutrient loadings scaled to match the loadings of Port Phillip Bay

Table B.2: List of components in Bay Model 2 (BM2) and the Integrated Generic Bay Ecosystem Model (IGBEM), compared to those in the Port Phillip Bay Integrated Model (PPBIM). All living and dead components have nitrogen pools, in IGBEM they also have carbon and phosphorous pools.

		Model	
Component	Codename	BM2 / IGBEM	PPBIM
Diatoms*	PL	Y	Y
Autotrophic Flagellates	AF	Y	
Picophytoplankton	PS	Y	Y
Dinoflagellates	DF	Y	Y
Free-living Pelagic Bacteria	PFB	Y	
Pelagic Attached Bacteria**	PAB	Y	
Heterotrophic Flagellates	HF	Y	
Microzooplankton	ZS	Y	Y
Large Omnivorous Zooplankton	ZL	Y	
Large Carnivorous Zooplankton	ZLC	Y	Y
Planktivorous Fish	FP	Y	
Piscivorous Fish	FV	Y	
Demersal Fish	FD	Y	
Demersal Herbivorous Fish	FG	Y	
Macroalgae	MA	Y	Y
Seagrass	SG	Y	Y
Microphytobenthos*	MB	Y	Y
Macrozoobenthos (Epifaunal carnivores)	MZ	Y	
Benthic (Epifaunal) Grazers	BG	Y	
Benthic Suspension Feeders	BF	Y	Y
Infaunal Carnivores	BC	Y	
Benthic Deposit Feeders	BD	Y	
Meiobenthos	OB	Y	
Aerobic Bacteria	AEB	Y	
Anaerobic Bacteria	ANB	Y	
Labile Detritus	DL	Y	Y
Refractory Detritus*	DR	Y	Y
DON	DON	Y	Y
Ammonia	NH	Y	Y
Nitrate	NO	Y	Y
Dissolved Silicate	Si	Y	Y
Dissolved Oxygen	O2	Y	Y***
Light	IRR	Y	Y
Salinity	SAL	Y	Y
Sediment Grain Types	PHI	Y	Y
Bottom Stress	STRESS	Y	Y
Porosity	POR	Y	Y
Volume	VOL	Y	Y

* Also have an internal silicon pool.
** Only present as a separate entity in BM2, in IGBEM there is a single pelagic bacteria component.
*** Handled as nitrogen fluxes scaled by the Redfield ratio N:O = 1:16

Table B.3: List of main terms used in the equations in the appendices C to F. All terms, variables, constants and expressions are defined in the relevant appendices, but this table may be a useful quick reference for the main terms and conventions.

Term	Meaning
E	Excretion (ammonia produced by a consumer)
F	Fishing (catch)
G	Growth
M	Mortality
P	Uptake
R	Remineralisation
S	Sediment chemistry (nitrification or denitrification, the subscript will denote which on a case-by-case basis)
W	Waste (detritus produced by a consumer)
XX	All doubles (and triples) refer to components of the model (see Table A3 for definitions). They do not represent multiplications at any time and any multiplications will be explicitly denoted by a "·".

Appendix C: Rate of change and process equations for Bay Model 2

Note: For quick reference, a list of the main terms used in the equations in this appendix is given in Appendix B, Table B.3.

C.1 Rate of change equations

Autotrophs

Rate of change for standard water column primary producer (PX):

$$\frac{d(PX_{\mathrm{w}})}{dt} = G_{\mathrm{PX_w}} - M_{\mathrm{lys,PX_w}} - \sum_{\substack{\mathrm{i=predator} \\ \mathrm{groups}}} P_{\mathrm{PX_w,i}} \tag{C.1}$$

$$\frac{d(PX_{\mathrm{sed}})}{dt} = -M_{\mathrm{nat,PX_{sed}}} \tag{C.2}$$

Where G_{PX} stands for the growth of PX, $M_{\mathrm{lys,PX}}$ is the loss of PX due to lysis, $M_{\mathrm{nat,PX}}$ is the natural mortality losses of PX when in the sediments and $P_{\mathrm{PX,I}}$ are the losses of PX due to predation. The equations for the benthic primary producers are slightly different. The rate of change of microphytobenthos is given by:

$$\frac{d(MB_{\mathrm{w}})}{dt} = G_{\mathrm{MB_w}} - M_{\mathrm{lys,MB_w}} - \sum_{\substack{\mathrm{i=water\ predator} \\ \mathrm{groups}}} P_{\mathrm{MB_w,i}} \tag{C.3}$$

$$\frac{d(MB_{\mathrm{sed}})}{dt} = G_{\mathrm{MB_{sed}}} - M_{\mathrm{nat,MB_{sed}}} - \sum_{\substack{\mathrm{i=sed\ predator} \\ \mathrm{groups}}} P_{\mathrm{MB_{sed},i}} \tag{C.4}$$

The macrophytes (MX) are restricted to the epibenthic layer and have no water column or sediment pools. The general form of their rate of change is as follows:

$$\frac{d(MX)}{dt} = G_{\mathrm{MX}} - M_{\mathrm{MX}} - \sum_{\substack{\mathrm{i=predator} \\ \mathrm{groups}}} P_{\mathrm{MX,i}} \tag{C.5}$$

The process equations for primary producers are outlined below and modifications to these equations due to mixotrophy in dinoflagellates are noted in the main text of chapter 2.

Invertebrate Consumers

Rate of change for a standard invertebrate consumer (CX):

$$\frac{d(CX)}{dt} = G_{\mathrm{CX}} - M_{\mathrm{CX}} - \sum_{\substack{\mathrm{i=predator}\\ \mathrm{groups}}} P_{\mathrm{CX,i}} - F_{\mathrm{CX}} \tag{C.6}$$

where F_{CX} stands for losses due to fishing on this group (this is set to zero in all standard runs of Bay Model 2 (BM2)). Invertebrate consumers are restricted to having only a water column or epibenthic or sediment pool and can not have pools in multiple layers.

Fish consumers

The following are the rates of change for a fish group (FX).

$$\frac{d(FX_{\mathrm{i,s}})}{dt} = G_{\mathrm{FX_{i,s}}} \tag{C.7}$$

$$\frac{d(FX_{\mathrm{i,r}})}{dt} = G_{\mathrm{FX_{i,r}}} \tag{C.8}$$

$$\frac{d(FX_{\mathrm{i,d}})}{dt} = T_{\mathrm{IMM,FX_i}} - T_{\mathrm{EM,FX_i}} - M_{\mathrm{FX_i}} - \sum_{\substack{\mathrm{j=predator}\\ \mathrm{groups}}} P_{\mathrm{FX,j}} - F_{\mathrm{FX_i}} \tag{C.9}$$

Where the subscript i represents age group i (there is one equation for each age class included), s stands for structural weight (skeletal and other material that can not be reabsorbed), r for reserve weight (fats and other tissues that can be broken down when food is scarce) and d for density. The *T* terms represent the movement of fish in to ($T_{\mathrm{IMM,Fxi}}$) and out of ($T_{EM,\mathrm{Fxi}}$) the cell. In addition there are short-term spawning and recruitment events which effect the various FX pools. At the same point each year (the exact day dependent on the fish and with a window of +/- 14 days) the fish spawn and the materials required to do this is removed from the reserve weight of FX. At this point all fish are aged one age class and the oldest age class leaves the bay (this is used in place of a plus group as it is more representative of the dynamics of Port Phillip Bay

(Gunthorpe et al. 1997)). Sometime later (the exact period dependent on the group) the recruits settle out and their weights and density are assigned to the youngest age class.

The amount of reserve weight (mg N per individual) that is used up during spawning is given by

$$s_{\mathrm{FX}_i} = \begin{cases} \mathrm{U}_{\mathrm{FX}_i} \cdot \boldsymbol{max}\left(0,\left(\mathrm{Z}_{\mathrm{FX}} \cdot (1+\mathrm{X}_{\mathrm{RS}}) \cdot FX_{\mathrm{i,s}} - \mathrm{Y}_{\mathrm{FX}}\right)\right) & , \quad FX_{\mathrm{i,s}} + FX_{\mathrm{i,r}} > (1+X_{\mathrm{RS}}) \cdot FX_{\mathrm{i,s}} \\ \mathrm{U}_{\mathrm{FX}_i} \cdot \boldsymbol{max}\left(0, \begin{pmatrix} \mathrm{Z}_{\mathrm{FX}} \cdot (1+\mathrm{X}_{\mathrm{RS}}) \cdot FX_{\mathrm{i,s}} + \left(FX_{\mathrm{i,s}} + FX_{\mathrm{i,r}}\right) \\ -\mathrm{Y}_{\mathrm{FX}} - (1+\mathrm{X}_{\mathrm{RS}}) \cdot FX_{\mathrm{i,s}} \end{pmatrix}\right) & , \quad FX_{\mathrm{i,s}} + FX_{\mathrm{i,r}} < (1+X_{\mathrm{RS}}) \cdot FX_{\mathrm{i,s}} \end{cases} \tag{C.10}$$

where $\mathrm{U}_{\mathrm{Fxi}}$ is the proportion of age group i that is reproductively mature, Z_{FX} is the fraction of the weight of FX used in spawning, Y_{FX} is the spawning function constant and X_{RS} is the ratio of structural to reserve weight in well fed fish.

The formulations for recruitment are given in the main text of chapter 2 and Table 2.2. It should be noted that the biomass of larvae of fish group FX in cell j at time t (L_{tj}), referred to in Table 2, is determined as follows:

$$L_{\mathrm{tj}} = \sum_{\mathrm{i=age\ class}} s_{\mathrm{FX_i}} \cdot FX_{\mathrm{i,d}} \tag{C.11}$$

Inanimate pools

Rates of change for ammonia (NH) in the water column is:

$$\frac{d(NH_{\mathrm{w}})}{dt} = -\sum_{\mathrm{i=PX_w}} P_{\mathrm{NH_w,i}} - P_{\mathrm{NH_w,MB_w}} - P_{\mathrm{NH_w,MA}} - P_{\mathrm{NH_w,PFB}} + \sum_{\mathrm{i=CX_w\ ,\ BF}} E_{\mathrm{i}} + \sum_{\mathrm{i=FX}} E_{\mathrm{i}} + \sum_{\substack{\mathrm{i=pelagic}\\ \mathrm{bacteria}}} E_{\mathrm{i}} - S_{\mathrm{NIT,PAB}} + R_{\mathrm{NET,w}} \tag{C.12}$$

and in the sediment:

$$\frac{d(NH_{\mathrm{sed}})}{dt} = R_{\mathrm{NET,sed}} - S_{\mathrm{NIT,sed}} - P_{\mathrm{NH_{sed},MB_{sed}}} - P_{\mathrm{NH_{sed},SG}} + \sum_{\mathrm{i \neq BF,CX_w}} E_{\mathrm{i}} \tag{C.13}$$

where $P_{\mathrm{NH,XX}}$ is the uptake of NH by the autroph XX, E_{CX} is the production of NH by the consumer CX, $S_{\mathrm{NIT,XB}}$ is the amount of NH lost due to nitrification by the bacteria

XB, R_{NET} is the amount of NH produced by denitrification.

The rates of change for nitrate (NO) in the water column is given by:

$$\frac{d(NO_{\mathrm{w}})}{dt} = -\sum_{\mathrm{i=PX_w}} P_{\mathrm{NO_w,i}} - P_{\mathrm{NO_w,MB_w}} - P_{\mathrm{NO_w,MA}} + S_{\mathrm{NIT,PAB}} \tag{C.14}$$

and in the sediment:

$$\frac{d(NO_{\mathrm{sed}})}{dt} = S_{\mathrm{NIT,sed}} - S_{\mathrm{DENIT,sed}} - P_{\mathrm{NO_{sed},MB_{sed}}} - P_{\mathrm{NO_{sed},SG}} \tag{C.15}$$

The rates of change of dissolved silicate (Si) in the water column is:

$$\frac{d(Si_{\mathrm{w}})}{dt} = R_{\mathrm{DSisol,w}} - \sum_{\mathrm{i=PL_w,MB_w}} P_{\mathrm{Si_w,i}} \tag{C.16}$$

and the rate of change of detrital silica (DSi) in the water column is given by:

$$\frac{d(DSi_{\mathrm{w}})}{dt} = \mathrm{X_{SiN}}\left(\sum_{\mathrm{i=PL_w,MB_w}}\left(M_{\mathrm{lys,i}} + \sum_{\mathrm{j=CX_w}} P_{\mathrm{i,j}}\right)\right) - R_{\mathrm{DSisol,w}} \tag{C.17}$$

where $\mathrm{X_{SiN}}$ is the Redfield ratio of silicon and nitrogen (set at 3.0 (Murray and Parslow 1997)) and R_{DSisol} is the amount of detrital silica remineralised. Note that the equations for $\mathrm{Si_{sed}}$ and $\mathrm{DSi_{sed}}$ are as for (C.16) and (C.17) except that $\mathrm{CX_{sed}}$ is used in the place of $\mathrm{CX_w}$ and MB is the only PX present in the sediment that uses Si.

The rates of change for dissolved oxygen (O2) in the water column is given by:

$$\frac{d(O2_{\mathrm{w}})}{dt} = \mathrm{X_{ON}}\left(\sum_{\mathrm{i=PX_w}} G_{\mathrm{i}} + G_{\mathrm{MB_w}} + G_{\mathrm{MA}} + \frac{G_{\mathrm{SG}}}{2} - \sum_{\substack{\mathrm{i\neq infauna,}\\ \mathrm{MZ,BG}}} E_{\mathrm{i}} - \sum_{\mathrm{i=FX}} E_{\mathrm{i}} - \sum_{\substack{\mathrm{i=pelagic}\\ \mathrm{bacteria}}} E_{\mathrm{i}} - R_{\mathrm{DON,w}}\right) \tag{C.18}$$

and in the sediment:

$$\frac{d(O2_{\mathrm{sed}})}{dt} = \mathrm{X_{ON}}\left(G_{\mathrm{MB_{sed}}} + \frac{G_{\mathrm{SG}}}{2} - \sum_{\substack{\mathrm{i=infauna,}\\ \mathrm{MZ,BG}}} E_{\mathrm{i}} - R_{\mathrm{DON,sed}}\right) \tag{C.19}$$

where $\mathrm{X_{ON}}$ is the Redfield ratio of oxygen and nitrogen (set at 16.0 (Murray and

Parslow 1997)) and R_{DON} is the DON lost due to remineralisation.

The rates of change of dissolved organic nitrogen (DON) in the water column is:

$$\frac{d(DON_{\mathrm{w}})}{dt} = W_{\mathrm{DON,w}} - R_{\mathrm{DON,w}} - P_{\mathrm{DON,PFB}} \tag{C.20}$$

and in the sediment:

$$\frac{d(DON_{\mathrm{sed}})}{dt} = W_{\mathrm{DON,sed}} - R_{\mathrm{DON,sed}} \tag{C.21}$$

where W_{DON} is the DON produced by bacteria, R_{DON} is the DON lost due to remineralisation and $P_{\mathrm{DON,PFB}}$ is the DON taken up by pelagic free bacteria (PFB).

The rates of change of labile detritus (DL) in the water column is:

$$\frac{d(DL_{\mathrm{w}})}{dt} = \sum_{\mathrm{i=CX_w}} W_{\mathrm{DL_w,i}} + \sum_{\mathrm{i=FX}} W_{\mathrm{DL_w,i}} + \sum_{\substack{\mathrm{i=pelagic}\\ \mathrm{bacteria}}} W_{\mathrm{DL_w,i}} + \sum_{\mathrm{i=PX_w}} M_{\mathrm{lys,i}} + M_{\mathrm{lys,MB_w}} + M_{\mathrm{MA}} - P_{\mathrm{DL_w,PAB}} - P_{\mathrm{DL_w,BF}} \tag{C.22}$$

and in the sediment:

$$\frac{d(DL_{\mathrm{sed}})}{dt} = \sum_{\mathrm{i=PX_{sed}}} M_{\mathrm{nat,i}} + M_{\mathrm{nat,MB_{sed}}} + M_{\mathrm{lys,MB_{sed}}} + M_{\mathrm{SG}} + \sum_{\mathrm{i=infauna}} \left(W_{\mathrm{DL,i}} - P_{\mathrm{DL_{sed},i}}\right) + \sum_{\mathrm{i=epifauna}} \left(W_{\mathrm{DL,i}} - P_{\mathrm{DL_{sed},i}}\right)$$
$$- \sum_{\mathrm{i=FX}} P_{\mathrm{DL_{sed},i}} \tag{C.23}$$

where $W_{\mathrm{DL,CX}}$ is the amount of DL in the waste products from consumer CX and $P_{\mathrm{DL,CX}}$ is the DL consumed by CX.

The rates of change of refractory detritus (DR) in the water column is given by:

$$\frac{d(DR_{\mathrm{w}})}{dt} = \sum_{\mathrm{i=FX}} W_{\mathrm{DR_w,i}} - \sum_{\mathrm{i=CX_w}} P_{\mathrm{DR_w,i}} - P_{\mathrm{DR_w,PAB}} - J_{\mathrm{DR}} \tag{C.24}$$

and in the sediment:

$$\frac{d(DR_{\mathrm{sed}})}{dt} = \sum_{\mathrm{i=infauna}} W_{\mathrm{DR_{sed},i}} - \sum_{\mathrm{i=infauna}} P_{\mathrm{DR_{sed},i}} + J_{\mathrm{DR}} \tag{C.25}$$

where $W_{\mathrm{DR,CX}}$ is the DR in the wastes of consumer CX, $P_{\mathrm{DR,CX}}$ is the amount of detritus consumed by CX, infauna includes sediment bacteria and J_{DR} is the amount of DR transferred from the water column to sediment pool due to the feeding activities of the benthic filter feeders.

C.2 Process equations

Growth of primary producers

$$G_{\mathrm{PX}} = \mu_{\mathrm{PX}} \cdot \delta_{\mathrm{irr}} \cdot \delta_{\mathrm{N}} \cdot \delta_{\mathrm{space}} \cdot PX \tag{C.26}$$

with μ_{PX} is the maximum growth rate, the nutrient limitation factor due to nitrogen is given by:

$$\delta_{\mathrm{N}} = \frac{DIN}{\kappa_{\mathrm{N,PX}} + DIN} \tag{C.27}$$

(where DIN=NH+NO) except for those primary producers which are also limited by the availability of Si then nutrient limitation is given by:

$$\delta_{\mathrm{N}} = \boldsymbol{min}\left(\frac{DIN}{\kappa_{\mathrm{N,PX}} + DIN}, \frac{Si}{\kappa_{\mathrm{Si,PX}} + Si} \right) \tag{C.28}$$

and light limitation is given by:

$$\delta_{\mathrm{irr}} = \boldsymbol{min}\left(\frac{IRR}{\kappa_{\mathrm{irr,PX}}}, 1 \right) \tag{C.29}$$

with the κ representing the half saturation constants for the respective processes, and space limitation as follows:

$$\delta_{\mathrm{space}} = 1 - \frac{PX}{\theta_{\mathrm{PXmax}}} \tag{C.30}$$

Using the above formulations for growth and nutrient limitation the nutrient uptake functions for the primary producer PX are given by:

$$P_{\mathrm{NH,PX}} = G_{\mathrm{PX}} \cdot \frac{NH}{\kappa_{\mathrm{NH,PX}} + NH} \cdot \frac{\kappa_{\mathrm{NH,PX}} + DIN}{DIN} \tag{C.31}$$

$$P_{\mathrm{NO,PX}} = G_{\mathrm{PX}} \cdot \frac{NO}{DIN} \cdot \frac{\kappa_{\mathrm{NH,PX}}}{\kappa_{\mathrm{NH,PX}} + NH} \tag{C.32}$$

where $\kappa_{NH,PX}$ is the half saturation constant for the uptake of NH. In addition, for PL and MB there is the uptake of Si as follows:

$$P_{\mathrm{Si,PX}} = \mathrm{X}_{\mathrm{SiN}} \cdot G_{\mathrm{PX}} \tag{C.33}$$

Growth of consumers

The growth of an invertebrate consumer (CX) is given by:

$$G_{\mathrm{CX}} = \left(\varepsilon_{\mathrm{CX}} \cdot \sum_{\substack{\mathrm{i=living} \\ \mathrm{prey}}} P_{\mathrm{i,CX}} + \sum_{\mathrm{j=DL,DR}} \left(P_{\mathrm{j,CX}} \cdot \varepsilon_{\mathrm{CX,j}} \right) \right) \cdot \delta_{\mathrm{space}} \cdot \delta_{\mathrm{o2}} \tag{C.34}$$

with ε_{CX} the growth efficiency of CX when feeding on live prey, $\varepsilon_{CX,j}$ the efficiency when feeding on detritus (DL treated separately to DR), space limitation given by:

$$\delta_{\mathrm{space}} = \begin{cases} 1 - \dfrac{\left(CX - \theta_{\mathrm{CXlow}}\right) \cdot \frac{\left(CX - \theta_{\mathrm{CXlow}}\right)}{\mathrm{CX} - \theta_{\mathrm{CXlow}} + \kappa_{\mathrm{CXsat}}}}{\left(CX - \theta_{\mathrm{CXlow}}\right) \cdot \frac{\left(CX - \theta_{\mathrm{CXlow}}\right)}{CX - \theta_{\mathrm{CXlow}} + \theta_{\mathrm{CXsat}}} + \kappa_{\mathrm{CXthresh}}} & , \quad CX = \mathrm{BF} \text{ and } CX > \theta_{\mathrm{CXlow}} \\ 1 & , \quad \text{otherwise} \end{cases} \tag{C.35}$$

where θ_{CXmax} is the maximum biomass per area allowed for CX, θ_{CXlow} is the crowding lower threshold, κ_{CXsat} is the crowding half saturation level, and $\kappa_{CXthresh}$ is the crowding threshold (this formulation is based on that of the European Regional Seas Ecosystem Model II (ERSEM II) (Blackford 1997)). The oxygen limitation in the standard runs of BM2 is given by:

$$\text{or} \quad \delta_{\mathrm{o2}} = \begin{cases} \dfrac{\gamma_{\mathrm{o2}}}{\gamma_{\mathrm{o2}} + \kappa_{\mathrm{CX,Mo2}}} & , \text{if epifauna or infauna} \\ 1 & , \text{if pelagic} \end{cases} \tag{C.36}$$

where γ_{o2} is the depth of the oxygen horizon and $\kappa_{CX,Mo2}$ is the half oxygen mortality depth.

The growth for each fish group, is calculated by equation of the same form as

(C.34), but per age group of each fish, the result is then apportioned to structural and reserve weight increases such that:

$$G_{\mathrm{FX}_{i,s}} = \Lambda \cdot G_{\mathrm{FX}_i} \tag{C.37}$$

$$G_{\mathrm{FX}_{i,r}} = (1-\Lambda) \cdot G_{\mathrm{FX}_i} \tag{C.38}$$

where

$$\Lambda = \begin{cases} \dfrac{\frac{1}{\mathrm{X_{RS}}} + \mathrm{X_{pR,FX}} \cdot \left(- \frac{FX_{i,r}}{\mathrm{X_{RS}} \cdot FX_{i,s}} \right)}{\frac{1}{\mathrm{X_{RS}}} + \cdot \frac{FX_{i,r}}{\mathrm{X_{RS}} \cdot FX_{i,s}}}, & \text{if} > 0 \text{ and } G_{\mathrm{FX}_i} > 0 \\ = 0 & \text{, otherwise} \end{cases} \tag{C.39}$$

with X_{RS} the maximum ratio of reserve to structural weight FX can have and $X_{pR,FX}$ is the relative degree to which FX concentrates on replenishing reserves rather than undergoing structural growth when underweight.

In the standard form of BM2 presented here the grazing term is given by:

$$P_{\mathrm{prey,CX}} = \frac{CX \cdot \mathrm{k_{CX}} \cdot \mathrm{p_{prey,CX}} \cdot prey}{1 + \mathrm{k_{CX}} \cdot \dfrac{\varepsilon_{\mathrm{CX}} \cdot \left(\sum_{\substack{\text{j=live prey}\\\text{groups}}} \mathrm{p_{j,CX}} \cdot \mathrm{j} \right) + \varepsilon_{\mathrm{CX,DL}} \cdot \mathrm{p_{DL,CX}} + \varepsilon_{\mathrm{CX,DR}} \cdot \mathrm{p_{DR,CX}}}{\mu_{\mathrm{CX}}}} \tag{C.40}$$

where “prey” is the group being consumed by CX, k_{cx} is the clearance rate of CX and $p_{prey,CX}$ is preference (or availability) of that prey for the predator CX. This last parameter is similar to the “vulnerability” parameters in ECOSIM (Christensen et al. 2000) and represents the fact that the entire prey population will not be available to the predators at any one time (some may be hiding for instance). The availability of the food is further modified if the spatial range of the predator and prey do not completely overlap (and so explicit spatial refuges exist). The available fish in cohort i of fish group FX (FX_i), for the fish eating cohorts of piscivorous (FV) and demersal (FD) fish (FY_j), is given by:

$$A_{\mathrm{FX}_i} = \begin{cases} \Sigma \mathrm{p_{FXi,FYj}} \cdot \dfrac{(FX_{i,s} + FX_{i,r}) * FX_{i,d}}{\mathrm{cell\_vol}}, & \Theta_{\mathrm{low,FY}} \cdot \mathrm{FY_{j,s}} \le FX_{s,i} \le \Theta_{\mathrm{up,FY}} \cdot \mathrm{FY_{j,s}} \\ 0 & \text{,otherwise} \end{cases} \tag{C.41}$$

where $\Theta_{low,FY}$ is the lower prey selection size limit for FY and $\Theta_{up,FY}$ is the upper prey selection size limit. The availability of benthic prey to their predators (fish and invertebrate alike) is calculated in a slightly different way and is as follows:

$$A_{\text{prey}} = prey \cdot \mathrm{d}_{\text{prey}} \tag{C.42}$$

where, if aerobic

$$\mathrm{d}_{\text{prey}} = \begin{cases} 0 & , \gamma_{\text{CX}} < \gamma_{\text{top}} \\ \frac{(\gamma_{\text{CX}} - \gamma_{\text{top}})}{(\gamma_{\text{o2}} - \gamma_{\text{top}})} & , \gamma_{\text{top}} < \gamma_{\text{CX}} < \gamma_{\text{o2}} \\ 1 & , \gamma_{\text{top}} < \gamma_{\text{o2}} < \gamma_{\text{CX}} \end{cases} \tag{C.43}$$

and if anaerobic

$$\mathrm{d}_{\text{prey}} = \begin{cases} 1 & , \gamma_{\text{CX}} < \gamma_{\text{top}} \\ \left(1 - \frac{(\gamma_{\text{CX}} - \gamma_{\text{top}})}{(\gamma_{\text{o2}} - \gamma_{\text{top}})}\right) & , \gamma_{\text{top}} < \gamma_{\text{CX}} < \gamma_{\text{o2}} \\ 0 & , \gamma_{\text{top}} < \gamma_{\text{o2}} < \gamma_{\text{CX}} \end{cases} \tag{C.44}$$

where γ_{CX} is the depth in the sediment that the predator CX can forage down to and γ_{top} is set to zero for all standard runs (as there is only one sediment layer).

Mortality and loss functions

The mortality terms for invertebrate consumers and autotrophs are in terms of lost biomass while those for fish refer to the number of individuals lost. Nevertheless the general form of the equations is the same (but the units of the coefficients obviously differ between the fish and other groups). The natural mortality term for group XX is given by

$$M_{\text{XX}} = \mathrm{m}_{\text{lin,XX}} \cdot XX + \mathrm{m}_{\text{quad,XX}} \cdot XX^{2} + (1 - \delta_{\text{o2}}) \cdot \mathrm{m}_{\text{o2,XX}} \cdot XX + \mathrm{m}_{\text{special,XX}} \cdot XX + \mathrm{m}_{\text{top,XX}} \cdot XX \tag{C.45}$$

where $m_{lin,XX}$ is the coefficient of linear mortality for XX, $m_{quad,XX}$ is the coefficient of quadratic mortality for the group XX, $m_{O2,XX}$ is the coefficient of oxygen dependent mortality and $m_{special,XX}$ is the special (additional) loss rate for XX. This rate of “special” mortality is usually set to zero, except in the following cases:

$$\mathrm{m}_{\mathrm{special,MA}} = STRESS \cdot \mathrm{m}_{\mathrm{STRESS}} \tag{C.46}$$

$$\mathrm{m}_{\mathrm{special,SG}} = DIN \cdot \mathrm{m}_{\mathrm{DIN}} \tag{C.47}$$

where m_{STRESS} and m_{DIN} are the coefficient of mortality due to mechanical stress and fouling by epiphytes, respectively. Lastly:

$$\mathrm{m}_{\mathrm{special,FX_i}} = \begin{cases} \dfrac{\mathrm{m}_{\mathrm{starve,FX}} \cdot \theta_{\mathrm{starve}} \cdot (1 + \mathrm{X}_{\mathrm{RS}}) \cdot \mathrm{FX}_{\mathrm{i,s}} - (\mathrm{FX}_{\mathrm{i,s}} + \mathrm{FX}_{\mathrm{i,r}})}{(1 + \mathrm{X}_{\mathrm{RS}}) \cdot \mathrm{FX}_{\mathrm{i,s}}} & \text{, if} > 0 \\ = 0 & \text{, otherwise} \end{cases} \tag{C.48}$$

with $m_{starve,FX}$ is the threshold ratio of reserve to structural weight at which death due to starvation is likely. The final term of equation (C.45) was adopted from ERSEM I (Bryant et al. 1995) to represent the impact of seabirds and other top predators and is given by:

$$\mathrm{m}_{\mathrm{top,XX}} = \mathrm{m}_{\mathrm{seabird,XX}} + \mathrm{m}_{\mathrm{shark,XX}} \tag{C.49}$$

While all the groups in the standard run of the model had a linear mortality term, some groups (the fish and higher trophic level zooplankton and benthic groups) suffered mortality described by a quadratic term. Only benthic consumers had oxygen dependent mortality, the macrophyte and fish groups had special mortality as shown above and m_{top} is only applied to the fish groups.

Fishing is another process that is only applied to fish in the standard runs. The amount caught at time t is given by:

$$F_{\mathrm{FX,t}} = C_{\mathrm{eff}} \cdot (FX_{\mathrm{s,i}} + FX_{\mathrm{r,i}}) \cdot FX_{\mathrm{di,}} \cdot \mathrm{q}_{\mathrm{FX_i}} \tag{C.50}$$

where q_{FXi} is the catchability of the ith age group of FX and

$$C_{\mathrm{eff}} = \begin{cases} \mathrm{m}_{\mathrm{FC,FX}} & \text{, standard runs} \\ \dfrac{\mathrm{m}_{\mathrm{FCmax,FX}}}{1 + e^{(-\mathrm{m}_{\mathrm{FCa}} \cdot F_{\mathrm{FX_i,t-1}})}} & \text{, effort model on} \end{cases} \tag{C.51}$$

with $m_{FC,FX}$ the coefficient of fishing mortality for FX, $m_{Fcmax,FX}$ the maximum fishing mortality allowed for FX and $m_{Fca,FX}$ the coefficient of spread for the fishing mortality of FX. As indicated by (C.50) and (C.51) the fishing implemented for standard runs is a simple catch equation.

The final loss term is one that is applied to the microscopic primary producers only and it represents lysis. The losses of a primary producer (PX) to lysis is formulated as follows:

$$M_{\mathrm{lys,PX}} = \frac{\mathrm{m}_{\mathrm{lys,PX}} \cdot PX}{\delta_{\mathrm{N}} + 0.1} \tag{C.52}$$

with $m_{lys,PX}$ the rate of lysis.

Waste processes

The production of waste products by invertebrate consumers and fish are handled in the same way, but in the case of fish the mortality term has to be converted from a density to a biomass before being used in the following equations. The production of labile detritus (DL) by consumer group XX is given by:

$$W_{\mathrm{DL}} = \begin{pmatrix} (1-\varepsilon_{\mathrm{XX}}) \cdot \Gamma_{\mathrm{XX}} \cdot \sum\limits_{\substack{\mathrm{i=living\ prey} \\ \mathrm{group}}} P_{\mathrm{i,XX}} + (1-\varepsilon_{\mathrm{XX,DL}}) \cdot \Gamma_{\mathrm{XX,DL}} \cdot P_{\mathrm{DL,XX}} \\ + (1-\varepsilon_{\mathrm{XX,DR}}) \cdot \Gamma_{\mathrm{XX,DR}} \cdot P_{\mathrm{DR,XX}} + \varphi_{\mathrm{XX}} \cdot \mathrm{M}_{\mathrm{XX}} \end{pmatrix} \cdot \mathrm{f}_{\mathrm{XX,DL}} \tag{C.53}$$

with φ_{XX} the proportion of mortality losses assigned to detritus, Γ_{XX} the proportion of the growth inefficiency of XX when feeding on live prey that is sent to detritus, $\Gamma_{XX,DL}$ the proportion of the growth inefficiency of XX when feeding on DL that is sent to detritus, $\Gamma_{XX,DR}$ the proportion of the growth inefficiency of XX when feeding on refractory detritus (DR) that is sent to detritus and $f_{XX,DL}$ is the proportion of the total detritus produced that is of the type DL. The same equation is used for the production of DR (W_{DR}), except that the final multiplication of the brackets by $f_{XX,DL}$ is replaced by multiplication by $(1-f_{XX,DL})$.

The other main waste product is excreted ammonia. The general formulation used for the production of ammonia by a consumer XX (invertebrate or fish) is as follows:

$$E_{\mathrm{XX}} = (1-\varphi_{\mathrm{XX}})\cdot M_{\mathrm{XX}} + (1-\varepsilon_{\mathrm{XX}})\cdot(1-\Gamma_{\mathrm{XX}})\cdot \sum_{\substack{\text{i=living prey}\\ \text{group}}} P_{\mathrm{i,XX}} + (1-\varepsilon_{\mathrm{XX,DL}})\cdot(1-\Gamma_{\mathrm{XX,DL}})\cdot P_{\mathrm{DL,XX}}$$
$$+(1-\varepsilon_{\mathrm{XX,DR}})\cdot(1-\Gamma_{\mathrm{XX,DR}})\cdot P_{\mathrm{DR,XX}} \qquad \text{(C.54)}$$

Physical processes

The only physical processes in BM2 that differ from those in the Port Phillip Bay Integrated Model (detailed in Murray and Parslow 1997, Walker 1997) are bioturbation, bioirrigation (detailed in the main text of chapters 1 and 2) and the calculation of the light attenuation coefficient. The formulation of the coefficient used in the Integrated Generic Bay Ecosystem Model (IGBEM) is adopted in BM2 and it is an expanded form of the one used in PPBIM. The coefficient is given by:

$$n = n_{\mathrm{w}} + n_{\mathrm{DON}}\cdot DON + n_{\mathrm{D}}\cdot(DL+DR) + n_{\mathrm{P}}\cdot\sum_{\mathrm{i=PX}} PX + n_{\mathrm{susp}}\cdot SUSP \qquad \text{(C.55)}$$

with n_{w} the background extinction coefficient, n_{DON} the contribution due to DON, n_{D} the contribution due to detritus, n_{P} the contribution due to phytoplankton (PX) and n_{susp} the contribution due to suspended sediments (SUSP).

Appendix D: Equations for dinoflagellates and mixotrophy in Bay Model 2

Note: For quick reference, a list of the main terms used in the equations in this appendix is given in Appendix B, Table B.3.

The formulation for the rate of change of dinoflagellates is:

$$\frac{d(DF)}{dt} = G_{\mathrm{DF}} - M_{\mathrm{DF}} - \sum_{\mathrm{i=DF,ZL}} P_{\mathrm{DF,i}} \tag{D.1}$$

where M_{DF} describes losses due to lysis suffered by the dinoflagellate pool (DF); $P_{\mathrm{DF,i}}$ are predation losses suffered by the dinoflagellate pool; and the total growth (G_{DF}) is given by

$$G_{\mathrm{DF}} = G_{\mathrm{phs,DF}} + \varepsilon_{\mathrm{DF}} \cdot G_{\mathrm{phag,DF}} \tag{D.2}$$

where photosynthetic growth ($G_{\mathrm{phs,DF}}$) is given by

$$G_{\mathrm{phs,DF}} = \mu_{\mathrm{DF}} \cdot \delta_{\mathrm{irr}} \cdot \delta_{\mathrm{N}} \cdot DF \tag{D.3}$$

while the phagotrophic contribution ($G_{\mathrm{phag,DF}}$) to total growth is given by

$$G_{\mathrm{phag,DF}} = \boldsymbol{min}\left(\sum_{\text{prey groups}} P_{\mathrm{i,DF}} \;\; , \;\; \frac{\mu_{\mathrm{DF}}}{\varepsilon_{\mathrm{DF}}} \cdot \delta_{\mathrm{irr}} \cdot (1 - \delta_{\mathrm{N}}) \cdot DF \right) \tag{D.4}$$

$\varepsilon_{\mathrm{DF}}$ is the assimilation efficiency of the mixotrophic dinoflagellates (set at 0.6); μ_{DF} is the temperature dependent maximum daily growth rate of the dinoflagellates (set at 0.5 mg N d^{-1}, Murray pers. com.), δ_{irr} is the light limitation factor, δ_{N} the nutrient limitation factor and $P_{\mathrm{i,DF}}$ the amount of prey group i grazed by the predator DF, which is calculated in the same way as for all other grazers in BM2. The light and nutrient limitation factors were largely calculated as for the pure autotrophs in BM2. Since there is strong evidence that dinoflagellates show an increase in efficiency at low light levels (Jeong et al. 1999, Li et al. 1999), there were some modifications made to the formulation of light limitation for this group. The modification is based on general observations that, due to increased efficiency at low light levels, mixotrophic growth rates are two- to three-fold higher than those of strict phototrophic growth under identical (low light) conditions (Skovgaard 1996, Legrand et al. 1998, Li et al. 1999). The final form of the light limitation factor (δ_{irr}) is:

$$\delta_{\mathrm{irr}} = \begin{cases} \boldsymbol{min}\left(IRR \cdot 0.01 + 0.018\,,1\right), & 0 < IRR \leq 0.1 \\ \boldsymbol{min}\left(\dfrac{IRR}{\kappa_{\mathrm{irr,DF}}},1\right), & \text{otherwise} \end{cases} \tag{D.5}$$

and the nutrient limitation factor as

$$\delta_{\mathrm{N}} = \frac{DIN}{\kappa_{\mathrm{N,DF}} + DIN} \tag{D.6}$$

where *DIN* represents the total inorganic nitrogen pool (made up of ammonia and nitrate).

Appendix E: Equations for bacteria and sediment chemistry in Bay Model 2

Note: For quick reference, a list of the main terms used in the equations in this appendix is given in Appendix B, Table B.3.

The general formulation for the dynamics of aerobic attached bacteria (where *XB* stands for Pelagic Attached Bacteria (PAB) or sediment bound Aerobic Bacteria (AEB)) is:

$$\frac{d(XB)}{dt} = G_{\mathrm{XB}} - M_{\mathrm{XB}} - \sum_{\substack{\mathrm{i=consumer}\\ \mathrm{groups}}} P_{\mathrm{XB,i}} \tag{E.1}$$

where the growth of the group of bacteria (G_{XB}) is given by

$$G_{\mathrm{XB}} = \mu_{\mathrm{XB}} \cdot XB \cdot \boldsymbol{max}\left(0\,\boldsymbol{,}\,(1-\rho_{\mathrm{XB}})^{\psi}\right) \tag{E.2}$$

and

$$\rho_{\mathrm{XB}} = \frac{XB}{(\tau_{\mathrm{DL,XB}} \cdot DL + \tau_{\mathrm{DR,XB}} \cdot DR) \cdot \delta_{\mathrm{O2}} \cdot \delta_{\mathrm{stim}}} \tag{E.3}$$

with μ_{XB} representing the maximum temperature-dependent daily growth rate for the group XB. *XB* is the current pool of bacteria and *DL* and *DR* are the labile and refractory detrital pools (all in mg N m^{-3}); $\tau_{\mathrm{DL,\ XB}}$ and $\tau_{\mathrm{DR,\ XB}}$ represent the maximum possible biomass of XB per biomass of that grade of detritus; ψ is the exponent dictating the reduction in growth as the bacterial pool approaches its maximum attainable levels (set to 3 in all standard runs) and δ_{O2} is the oxygen limitation factor, which is given by:

$$\delta_{\mathrm{O2}} = \begin{cases} \dfrac{\gamma_{\mathrm{O2}}}{\gamma_{\mathrm{O2}} + \gamma_{\mathrm{XB}}}, & \text{XB benthic} \\ 1, & \text{otherwise} \end{cases} \tag{E.4}$$

where γ_{XB} is the half oxygen mortality depth for XB, and the oxygen horizon (γ_{O2}) is given by:

$$\gamma_{O2} = \frac{2 \cdot O2_{sed} \cdot \gamma_{sed}}{O2_{bw}} \tag{E.5}$$

with $O2_{sed}$ the concentration of oxygen in the sediments, $O2_{bw}$ the concentration in the bottom water and γ_{sed} the depth of the sediment layer considered in the model. Finally δ_{stim} indicates the degree of stimulation of the bacteria by bioturbation and it is calculated as follows:

$$\delta_{stim} = \begin{cases} \dfrac{\delta_{te} \cdot 250 \cdot (POR\text{-}0.225)}{193.75}, & \text{XB benthic} \\ 1, & \text{otherwise} \end{cases} \tag{E.6}$$

Use of a compound effect of enhanced bioturbation (δ_{te} calculated in the same way as for IGBEM – chapter 1), and porosity (POR) is based on observations by Alongi (1998) and the relationship detailed by Blackburn (1987). Using equations (E.2) to (E.5), the utilisation of labile detritus by aerobic bacteria is given by:

$$P_{DL,XB} = G_{XB} \cdot \frac{\rho_{XB} \cdot \tau_{XB,DL} \cdot DL}{XB \cdot \varepsilon_{XB,DL}} \tag{E.7}$$

where $\varepsilon_{XB,DL}$ is the assimilation efficiency of the bacteria on labile detritus. The uptake of refractory detritus is calculated similarly. The natural mortality term (M_{XB}) is as for the other invertebrates (Appendix B), but the term representing predation losses to predator group i ($P_{XB,i}$) is given by:

$$P_{XB,i} = P_{DL,i} \cdot \rho_{XB} \cdot \tau_{XB,DL} + P_{DR,i} \cdot \rho_{XB} \cdot \tau_{XB,DR} \tag{E.8}$$

The waste handling equations for bacteria are also different to those for other invertebrates since wastes are channelled into DON not DL. All of the equations for the Anaerobic Bacteria (ANB) are as for XB here, except that any δ_{O2} factors in the equations are replaced by (1-δ_{O2}). Adopting these equations for the attached bacteria made it easier to identify a method of introducing dynamic flexibility to the empirical nitrification-denitrification model proposed by Murray and Parslow (1999a) for PPBIM.

To integrate a more interactive form of the processes governing nitrification and denitrification into BM2, the empirical sediment chemistry model used in PPBIM (Murray and Parslow 1999a) is linked directly to the activities of sediment bacteria and infauna. The amount of ammonia produced by the remineralisation of DON (R_{DON}) is handled as in PPBIM, that is:

$$R_{\mathrm{DON}} = \Phi \cdot DON \cdot POR \qquad \text{(E.9)}$$

where Φ is the temperature-dependent rate of breakdown for DON (set at 0.00176 d^{-1}, Murray pers. com.). In PPBIM, equations similar to (E.9) were used to calculate the production of ammonia due to the breakdown of DL and DR (Murray and Parslow 1997). This is not the case in BM2, where the production of the remainder of the ammonia is dependent upon the activity of sediment dwelling fauna and flora. Thus, the total ammonia available for nitrification and denitrification (R_{NET}) is:

$$R_{\mathrm{NET}} = \boldsymbol{max}\left(0\,, R_{\mathrm{DON}} + E_{\mathrm{AEB}} + E_{\mathrm{ANB}} + \xi \cdot \left(E_{\mathrm{OB}} + E_{\mathrm{BD}}\right) - P_{\mathrm{NH,MB}}\right) \qquad \text{(E.10)}$$

where $P_{\mathrm{NH,MB}}$ is the uptake of NH by MB (see equations for autotrophs in Appendix C), E_{XX} is the ammonia released by XX and ξ is the fraction of the excreted NH by infauna that contributes available nitrogen for nitrification and denitrification (set to 0.95 in the standard runs). The form of E_{XX} for OB and BD is of the general form given for heterotrophs in Appendix B, but that for AEB and ANB is slightly different and is given by:

$$E_{\mathrm{XB}} = P_{\mathrm{DL,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DL}}\right) + P_{\mathrm{DR,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DR}}\right) + M_{\mathrm{XB}} - W_{\mathrm{DON}} - W_{\mathrm{DR}} \qquad \text{(E.11)}$$

where E_{XB} is the release of NH by XB, $\varepsilon_{\mathrm{XB,DX}}$ is the efficiency of XB on the detritus fraction DX, and the production of DON (W_{DON}) and DR (W_{DR}) are calculated as follows:

$$W_{\mathrm{DON}} = \left(P_{\mathrm{DL,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DL}}\right) + P_{\mathrm{DR,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DR}}\right) + M_{\mathrm{XB}} \cdot \varphi_{\mathrm{XB}}\right) \cdot \mathrm{f}_{\mathrm{XB,DON}} \qquad \text{(E.12)}$$

$$W_{\mathrm{DR}} = \left(P_{\mathrm{DL,XB}} \cdot \left(1 - \varepsilon_{\mathrm{XB,DL}}\right) + M_{\mathrm{XB}} \cdot \varphi_{\mathrm{XB}}\right) \cdot \mathrm{f}_{\mathrm{XB,DR}} \qquad \text{(E.13)}$$

where φ_{XB} indicates the fraction of the losses of XB due to natural mortality that are not released as NH and $f_{XB,DX}$ is the fraction of the products of growth inefficiency and mortality directed to the detritus fraction DX. Using equation (E.10) the processes of nitrification and denitrification were completed using the form of the empirical model of Murray and Parslow (1999a), giving nitrification (S_{NIT}) as:

$$S_{NIT} = R_{NET} \cdot \theta_{DMAX} \cdot \boldsymbol{max}\left(0\, , 1 - \frac{R_{NET} \cdot \gamma_{SED}}{\mathrm{r0}} \right) \tag{E.14}$$

and denitrification (S_{DENIT}) as:

$$S_{DENIT} = S_{NIT} \cdot \boldsymbol{min}\left(1\, , \frac{R_{NET} \cdot \gamma_{SED}}{\theta_{rD}} \right) \tag{E.15}$$

where θ_{DMAX} is the maximum rate of denitrification (set at 0.25, Murray pers. com.), θ_{r0} is the temperature-dependent minimum rate of respiration that supports nitrification (set at 200, Murray and Parslow 1997) and θ_{rD} (set at 10, Murray and Parslow 1997) is the peak of the nitrification-denitrification curve (as defined by Murray and Parslow 1999a). This general form is adopted from PPBIM due to its demonstrated performance and robustness (Murray and Parslow 1999a, chapter 1).

The more interactive representation of sediment processes lead to a minor modification to the bioirrigation equations. The formulation remained unchanged from that of PPBIM (Walker 1997) and IGBEM (chapter 1) for the majority of groups, but for oxygen it became:

$$O2_{bw,t+1} = \frac{\left(O2_{bw,t} \cdot VOL_{bw} + O2_{sed,t} \cdot VOL_{por} \right)}{VOL_{bw} + VOL_{por}} + e^{-\phi_{irr} \cdot \left(\frac{1}{VOL_{bw}} + \frac{1}{VOL_{por}} \right)} \cdot \left(O2_{bw,t} - \frac{\left(O2_{bw,t} \cdot VOL_{bw} + O2_{sed,t} \cdot VOL_{por} \right)}{VOL_{bw} + VOL_{por}} \right) \tag{E.16}$$

$$O2_{sed,t+1} = O2_{sed,t} - \frac{VOL_{bw}}{VOL_{por}} \cdot \left(O2_{bw,t+1} - O2_{bw,t} \right) \tag{E.17}$$

where ϖ_{irr} is the exchange rate due to irrigation (calculated as for IGBEM (chapter 1)),

$O2_{\mathrm{SED},t}$ is the concentration of oxygen in the sediment at time t, $O2_{\mathrm{bw},t}$ is the concentration of oxygen in the bottom water at time t, VOL_{bw} is the volume of the bottom water layer and the porewater volume above the oxygen horizon is given by:

$$VOL_{\mathrm{por}} = POR \cdot \frac{\gamma_{\mathrm{o2}} \cdot \chi_{\mathrm{cell}}}{VOL_{\mathrm{sed}}} \tag{E.18}$$

with VOL_{sed} being the volume of the entire sediment layer and χ_{cell} is the area of the cell. All other parts of the transport model were as implemented in IGBEM (chapter 1).

Appendix F: Equations for fish movement in Bay Model 2

Note: For quick reference, a list of the main terms used in the equations in this appendix is given in Appendix B, Table B.3.

Fish movement (in terms of the density d of fish group FX, age class i, in cell j) in the standard set-up of BM2 is given by:

$$FX_{\text{i,d,j}} = \begin{cases} FX_{\text{i,tot}} \cdot \left(\vartheta \cdot \left(\mathbf{FDEN}_{\text{j,qrt+1,FX}} - \mathbf{FDEN}_{\text{j,qrt,FX}}\right) + \mathbf{FDEN}_{\text{j,qrt,FX}}\right), & qrt < 4 \\ FX_{\text{i,tot}} \cdot \left(\vartheta \cdot \left(\mathbf{FDEN}_{\text{j,1,FX}} - \mathbf{FDEN}_{\text{j,qrt,FX}}\right) + \mathbf{FDEN}_{\text{j,qrt,FX}}\right), & qrt = 4 \end{cases} \tag{F.1}$$

where $FX_{\text{i,tot}}$ is the total number of FX in age class i in the entire system (that is the sum over all cells), ϑ is the proportion of the current quarter of the year which has already passed, $\mathbf{FDEN}_{\text{j,qrt,FX}}$ is the proportion of the population of FX found in cell j in the qrt quarter of the year.

For the forage and density dependent fish movement scheme, the following formulation is used:

$$G_{\text{FX,i,j,potential}} = \begin{cases} g_{\text{roc\_mult}} \cdot G_{\text{FX,i,j}}, & G_{\text{FX,i,j}} > g_{\text{thesh}} \\ \dfrac{G_{\text{FX,i,j}}}{g_{\text{roc\_mult}}}, & \text{otherwise} \end{cases} \tag{F.2}$$

$$G_{\text{FX,i,tot}} = \sum_{\text{all j}} G_{\text{FX,i,j}} \tag{F.3}$$

$$FX_{\text{i,d,j}} = \frac{FX_{\text{i,tot}} \cdot G_{\text{FX,i,j,potential}}}{G_{\text{FX,i,tot}}} \tag{F.4}$$

where $G_{\text{FX,i,j,potential}}$ is a measure of the potential attractiveness of the cell j based on the available forage, $G_{\text{FX,i,j}}$ is calculated as of G_{CX} in equation C.34, $g_{\text{roc\_mult}}$ is a constant reflecting how much more attractive a sight with forage sufficient to support FX_i is over a site with poor food resources and g_{thresh} is the potential growth rate (as an index of the quality of the resources) where FX_i switch from finding the site desirable to undesirable.