Supplementary Information

Modelling the impacts of semi-intensive aquaculture on the foodweb functioning of a Nile Delta coastal lake

M Bocci, R Pastres, S Kholeif, D Dalla Barba and D Brigolin

African Journal of Marine Science 2017, 39(3): 237-249
http://dx.doi.org/10.2989/1814232X.2017.1362354

Appendix S1: Biogeochemical model (BGM) for Lake Burullus, Egypt: model formulation and parameterization

Table S1: Model state variables

Variable	Description	Unit	No.
NO_3^-	Nitrate	mgN l^{-1}	(1)
NH_4^+	Ammonia	mgN l^{-1}	(2)
DIP	Dissolved inorganic phosphorus	mgP l^{-1}	(3)
Zoo_1	Zooplankton carbon	mgC l^{-1}	(4)
Phy_1	Phytoplankton Functional Group 1 – carbon	mgC l^{-1}	(5)
Phy_2	Phytoplankton Functional Group 2 – carbon	mgC l^{-1}	(6)
O_2	Dissolved oxygen	mgO_2 l^{-1}	(7)
Det_C	Carbon content in detritus	mgC l^{-1}	(8)
Det_N	Nitrogen content in detritus	mgN l^{-1}	(9)
Det_P	Phosphorous content in detritus	mgP l^{-1}	(10)
Sed_C	Carbon content in sediment	mgC l^{-1}	(11)
Sed_N	Nitrogen content in sediment	mgN l^{-1}	(12)
Sed_P	Phosphorous content in sediment	mgP l^{-1}	(13)

Table S2: Mass-balance equations

Reaction terms—	
$\frac{d[Phy^i]}{dt} = G_{Phy^i} - R_{Phy^i} - M_{Phy^i} - Grz_{Phy^i} - sed_{Phy^i}$	(1)
$\frac{d[Zoo]}{dt} = Eff_{PZ} \cdot \sum_i Grz_{Phy} - Grzz - M_{Zoo} - Exc_{Zoo} - sed_{Zoo}$	(2)
$\frac{d[NO_3^-]}{dt} = -r_{nc} \cdot G_{Phy^i} \cdot \frac{[NO_3^-]}{[N_{tot}]} + Nitr \quad , [N_{tot}] = [NO_3^-] + [NH_4^+]$	(3)
$\frac{d[NH_4^+]}{dt} = -r_{nc} \cdot G_{Phy^i} \cdot \frac{[NH_4^+]}{[N_{tot}]} + r_{nc} \cdot (R_{Phy^i} + Exc_{Zoo^k}) + dec_{DetN} + dec_{SedN} - Nitr$	(4)
$\frac{d[DIP]}{dt} = -r_{pc} \cdot G_{Phy^i} + r_{pc} \cdot (R_{Phy^i} + Exc_{Zoo^k}) + dec_{DetP} + dec_{SedP}$	(5)
$\frac{d[Det_C]}{dt} = (1 - Eff_{PZ^k}) \cdot Grz_{Phy^i} + (1 - Eff_{ZZ}) \cdot Grzz + M_{zoo^k} + M_{Phy^i} - dec_{DetC} - sed_{SedC}$	(6)
$\frac{d[Det_N]}{dt} = r_{nc} \cdot \left[(1 - Eff_{PZ^k}) \cdot Grz_{Phy^i} + (1 - Eff_{ZZ}) \cdot Grzz + M_{zoo^k} + M_{Phy^i}\right] - dec_{DetN} - sed_{SedN}$	(7)
$\frac{d[Det_P]}{dt} = r_{pc} \cdot \left[(1 - Eff_{PZ^k}) \cdot Grz_{Phy^i} + (1 - Eff_{ZZ}) \cdot Grzz + M_{zoo^k} + M_{Phy^i}\right] - dec_{DetP} - sed_{SedP}$	(8)
$\frac{d[Sed_C]}{dt} = sed_{SedC} - dec_{SedC}$	(9)
$\frac{d[Sed_N]}{dt} = sed_{SedN} - dec_{SedN}$	(10)
$\frac{d[Sed_P]}{dt} = sed_{SedP} - dec_{SedP}$	(11)
$\frac{d[O_2]}{dt} = r_{oc} \cdot (G_{Phy^i} - R_{Phy^i} - dec_{DetC} - dec_{SedC}) - r_{no} \cdot Nitr + K_{rea}(DO_{sat} - [O_2])$	(12)

i = 1,2: where 1 = Phytoplankton Functional Group 1, and 2 = Phytoplankton Functional Group 2

Table S3: Functional expressions

$G_{Phy^i} = GP_{max\,Phy^i} \cdot (F_I^{\,i} \cdot F_T^{\,i} \cdot F_{Nut}^{\,i}) \cdot [Phy^i]$	(1)
$R_{Phy^i} = K_{BR\,Phy^i} \cdot F_T \cdot [Phy^i] + K_{PR\,Phy^i} \cdot GP_{max\,Phy^i} \cdot F_T \cdot [Phy^i]$	(2)
$M_{Phy^i} = Km_{Phy^i} \cdot [Phy^i]$	(3)
$Grz_{Phy^i} = \sum_k K_{gr\,Zoo} \cdot \frac{[Phy^i]}{K_{g\,Phy^i} + [Phy^i]} \cdot [Zoo]$	(4)
$sed_{Phy^i} = K_{sed\,Phy^i} \cdot [Phy^i]$	(5)
$Grzz = K_{gr\,Zoo} \cdot \frac{[Zoo]}{K_{g\,Zoo} + [Zoo]} \cdot [Zoo]$	(6)
$M_{Zoo} = Km_{Zoo} \cdot [Zoo]$	(7)
$Exc_{Zoo} = Kesc_{Zoo} \cdot [Zoo]$	(8)
$sed_{Zoo} = K_{sedZoo} \cdot [Zoo]$	(9)
$sed_{DetX} = K_{sedDetX} \cdot [Det_X]$, X = C, N, P	(10)
$dec_{DetX} = K_{decDetX} \cdot A_{rrt} \cdot F_{oxy} \cdot [Det_X]$, X = C, N, P	(11)
$Nitr = K_{nit} \cdot A_{rrt} \cdot [NH_4^{\,+}]$	(12)
$DO_{sat} = 14.6244 - 0.367134 \cdot T + 0.0044972 \cdot T^2 - 0.0966 \cdot Sal + 0.00005 \cdot T \cdot Sal + 0.0002739 \cdot Sal^2$	(13)

i = 1,2: where 1 = Phytoplankton Functional Group 1, and 2 = Phytoplankton Functional Group 2

Table S3: (continued)	
$F_I{}^i = \frac{I_z}{I_{opt}{}^i} \cdot \exp\left[1-(I_z/I_{opt}{}^i)\right]$, where $I_z = I_{sun} \cdot \exp\left[-k_{est} \cdot \frac{depth}{2}\right]$	(14)
$F_T{}^i = \left[\frac{T_{max}{}^i - T_m}{T_{max} - T_{opt}{}^i}\right]^{b \cdot (T_{max}{}^i - T_{opt}{}^i)} \cdot \exp\left[b \cdot \left(T_m - T_{opt}{}^i\right)\right]$, where $T_m = \min(T, T_{max}{}^i)$	(15)
$F_{Nut}{}^i = \min(F_N{}^i, F_P{}^i)$	(16)
$F_N{}^i = \frac{N_{tot}}{K_N{}^i + N_{tot}}$, where $N_{tot} = [NO_3{}^-] + [NH_4{}^+]$	(17)
$F_P{}^i = \frac{[DIP]}{K_P{}^i + [DIP]}$	(18)
$A_{rrt} = 1.07^{(T-20)}$	(20)
$F_{oxy} = \frac{[O_2]}{K_{OD} + [O_2]}$	(21)

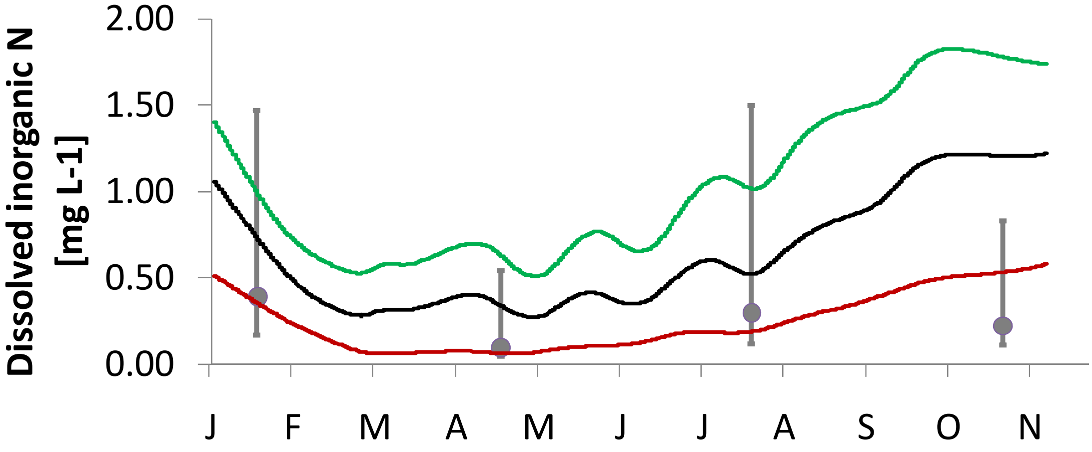
i = 1,2: where 1 = Phytoplankton Functional Group 1, and 2 = Phytoplankton Functional Group 2

Table S4: Parameters used in the biogeochemical model (BGM)

Name	Value	Unit	Description	Reference
			Phytoplankton	
Commons—				
r_{nc}	0.15	(mgN/mgC)	Nitrogen/Carbon ratio in phytoplankton	Pastres et al. (2001)
r_{pc}	0.023	(mgP/mgC)	Phosphorous/Carbon ratio in phytoplankton	Pastres et al. (2001)
k_{sedPhy}	0.0016	(h^{-1})	Phytoplankton sedimentation rate	Pastres et al. (2001)
Phytoplankton Functional Group 1 (i = 1)—				
GP_{maxPhy}	0.1	(h^{-1})	Maximum growth rate at $T = T_{opt}$	Lovato et al. (2013)
K_{mPhy}	0.005	(h^{-1})	Mortality rate	Pastres et al. (2001)
K_{BRPhy}	0.004	(h^{-1})	Basal-respiration rate	Lovato et al. (2013)
K_{PRPhy}	0.02	(h^{-1})	Photo-respiration rate	Lovato et al. (2013)
K_N	0.02	(mgN^{-1})	Half-saturation value for N limitation	Sarthou et al. (2005)
K_P	0.005	($mgP\ l^{-1}$)	Half-saturation value for P limitation	Sarthou et al. (2005)
T_{opt}	25	(°C)	Optimal temperature for growth	Lovato et al. (2013)
T_{max}	35	(°C)	Temperature-inhibition threshold for growth	This study
I_{opt}	100	(W/m^2)	Light-intensity parameter	Sakshaug and Andresen (1986)
Phytoplankton Functional Group 2 (i = 2)—				
GP_{maxPhy}	0.08	(h^{-1})	Maximum growth rate at $T=T_{opt}$	Lovato et al. (2013)
K_{mPhy}	0.005	(h^{-1})	Mortality rate	Pastres et al. (2001)
K_{BRPhy}	0.004	(h^{-1})	Basal-respiration rate	Lovato et al. (2013)
K_{PRPhy}	0.02	(h^{-1})	Photo-respiration rate	Lovato et al. (2013)
K_N	0.02	($mgN\ l^{-1}$)	Half-saturation value for N limitation	Sarthou et al. (2005)
K_P	0.005	($mgP\ l^{-1}$)	Half-saturation value for P limitation	Sarthou et al. (2005)
T_{opt}	20	(°C)	Optimal temperature for growth	Lovato et al. (2013)
T_{max}	30	(°C)	Temperature-inhibition threshold for growth	Lovato et al. (2013)
I_{opt}	74.8	(W/m^2)	Light-intensity parameter	Pastres et al. (2001)

Table S4: (continued)

Name	Value	Unit	Description	Reference
			Zooplankton	
K_{gr1Phy}	0.04	(h^{-1})	Zooplankton maximum grazing rate on phytoplankton	Sarthou et al. (2005)
Km_{zoo1}	0.001	(h^{-1})	Zooplankton mortality rate	Lovato et al. (2013)
Eff_{PZ1}	0.5		Zooplankton digestion efficiency	Pastres et al. (2001)
$Kesc_{zoo1}$	0.002	(h^{-1})	Zooplankton excretion rate	Pastres et al. (2001)
K_{gphy1}	4	(mgC-Phy l^{-1})	Half-saturation constant for grazing on Phytoplankton Functional Group 1	This study
K_{gphy2}	4	(mgC-Phy l^{-1})	Half-saturation constant for grazing on Phytoplankton Functional Group 2	This study
K_{sedzoo}	0.00016	(h^{-1})	Zooplankton sinking velocity	Pastres et al. (2001)
			Other parameters	
K_{nit}	0.001	(h^{-1})	Nitrification rate at 20°C (water column)	This study
K_{rea}	0.04584	(h^{-1})	Reaeration rate at 20°C	Pastres et al. (2001)
b	0.1157	$(°C^{-1})$	Exponential coefficient of the temperature functional expression	Pastres et al. (2001)
r_{oc}	2.66	(mgO/mgC)	Oxygen/Carbon ratio	Pastres et al. (2001)
r_{no}	4.5	(mgO/mgN)	Oxygen/Nitrogen ratio	Pastres et al. (2001)
$K_{sedDetX}$	0.016	(h^{-1})	Detritus sinking velocity	Pastres et al. (2001)
$K_{decDetX}$	0.0048	(h^{-1})	Detritus degradation rate at 20°C (water column)	Pastres et al. (2001)
K_{OD}	2	(mgO/l)	Half-saturation value for oxygen	Pastres et al. (2001)
I_Z	1	(m^{-1})	Light-extinction coefficient	Pastres et al. (2001)
K_{par}	0.46		Conversion value for solar radiation total to par to W/m^2	Ciavatta et al. (2008)



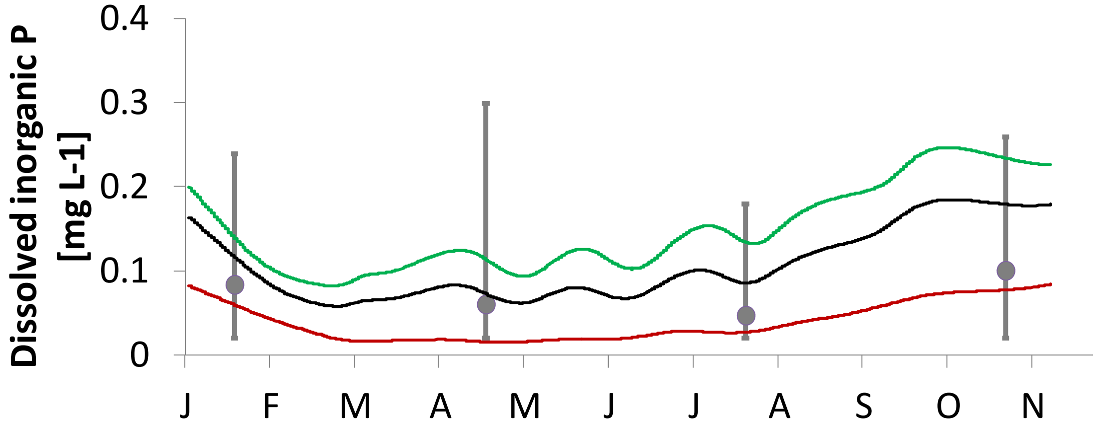


Figure S1: Field-data BGM comparison. DIN and DIP concentrations are those observed in Lake Burullus, Egypt, monthly, in 2003 (Okbah 2005); points = mean, bars = SD. The eastern basin is shown in red, central basin in black, and western basin in green

Appendix S2: Foodweb model (FWM) for Lake Burullus, Egypt

• **Foodweb model (FWM) structure**

The FWM for Lake Burullus considered three classes of compartments: primary producers, consumers and dead organic matter (detritus). The respective mass-balance equations for these are as follows:

Primary producers

$$P_y - \sum_u Pr_{y \to u} - M_y = 0 + \varepsilon \qquad \text{(Eqn S1)}$$

For a primary producer *y*, net production (P_y) must balance the sum of the outputs (consumption by other groups ($\sum_u Pr_{y \to u}$) and natural mortality (M_y).

Consumers

$$\sum_x Pr_{x \to y} - \sum_u Pr_{y \to u} - M_y - C_y = 0 + \varepsilon \qquad \text{(Eqn S2)}$$

For a consumer *y*, consumption (Q_y= $\sum_x Pr_{x \to y}$) representing the total energy input from its x prey items, including the eventual sources of food external to the system, must balance the sum of the outputs, consisting of: respiration (R_y), faeces (F_y), predation by its predator groups *u* (P_y= $\sum_u Pr_{y \to u}$), natural mortality (M_y) and catches (C_y , if any).

Organic detritus

$$\sum_y M_y + \sum_y F_y + INP_{DET} - \sum_u Pr_{y \to u} - EXP_{DET} = 0 + \varepsilon \qquad \text{(Eqn S3)}$$

For organic detritus, the total energy input deriving from natural mortality (M_y), faeces (F_y) and input from the external environment (INP_{DET} , if any), must be balanced by detritus predation by all the detritivorous groups:

$$\sum_u Pr_{y \to u}$$

as well as the detritus export to the external environment (EXP_{DET} , if any).

• **Ecological network analysis – considered indicators**

Ulanowicz (1980, 2000) defined Ascendency as a measure of both the size and the organizational status of the network of exchanges that occur in an ecosystem, system structure organisation (AMI) and the system size (TST). Thus, Ascendency is determined as follows:

$$\mathrm{ASC} = \sum_{i,j} T_{i,j} \log\left(\frac{T_{ij} \cdot TST_{.}}{\sum_{k} T_{ik} \sum_{l} T_{lj}} \right)$$

Ulanowicz (2000) also defined Capacity as the residual freedom in a system (functional indeterminacy or system functional diversity). Capacity is determined as follows:

$$CAP = -\sum_{i,j} T_{i,j} \log\left(\frac{T_{ij.}}{T} \right)$$

Total System Throughput (TST) is given by the total amount of flows exchanged in the network, and is the sum of the throughput of each compartment; it represents a useful measure of the activity and the size of the ecosystem (Ulanowicz 1980, 1986):

$$\mathrm{TST} = \sum_{i,j}^{n+2} T_{i,j}$$

where –

i is the prey and *j* the predator; *n+2* are respectively export (*Ei*) and dissipation vectors (*Ri*).

The Finn Cycling Index (*CI*) (Finn 1976) is the classic index used to evaluate the capability of the system to recycle matter and energy; it is determined as follows:

$$\mathrm{C}I = \sum_{i=1}^{n} \frac{S_i}{TST} \cdot \frac{l_{ii} - 1}{l_{ii}}$$

where –

S_i is the inflow in the compartment *i*; l_{ii} is the diagonal element of the fractional inflow matrix, obtained by normalising its columns by dividing each coefficient T_{ij} by its corresponding inflow S_i. The Finn *CI* represents the percentage of the total ecosystem activity that is devoted to cycling (i.e. flowing through cyclic pathways) in the system and it is a measure of retentiveness.

Table S5: Interaction matrix used in the FWM

	1-PHP	2-PHB	3-ZOP	4-MEI	5-MDT	6-MHR	7-MFF	8-MMF	9-MZC	10-NHZ	11-NMI	12-NMA	13-NDT	14-NHP	15-BRD
1-PHP			1			1	1								
2-PHB				1	1	1	1	1			1	1	1		
3-ZOP			1				1	1		1					
4-MEI			1	1	1		1	1	1	1	1	1	1		1
5-MDT									1	1	1	1			1
6-MHR									1	1	1	1			1
7-MFF									1		1	1			1
8-MMF									1		1	1		1	1
9-MZC									1					1	1
10-NHZ											1			1	1
11-NMI												1		1	1
12-NMA												1		1	1
13-NDT														1	1
14-NHP															1
15-BRD															
16-DET			1	1	1		1	1		1	1		1		

Table S6: FWM inputs for the western basin. Where two values are given, the first refers to the 'no aquaculture' (NA) scenario and the second to the 'aquaculture' (A) scenario. P/B = production/biomass; Q/B = consumption biomass; AE = assimilation efficiency; R = respiration; GE = growth efficiency; EE = ecotrophic efficiency

Input	Biomass kJ m^{-2}	Landings kJ m^{-2} d^{-1}	P/B d^{-1}	Q/B d^{-1}	AE	R	GE	EE
1-PHP	2.63 / 3.82		2.26			0.3–0.5	0.1–0.5	0.0–0.95
2-PHB	2476.40		0.003			0.3–0.5	0.1–0.5	0.0–0.95
3-ZOP	104.00		0.013		0.5–0.9	0.3–0.5	0.1–0.5	0.0–0.95
4-MEI	21.77			0.19	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
5-MDT	30.72		0.02		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
6-MHR	64.92		0.02		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
7-MFF	23.89		0.013		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
8-MMF	5.47		0.025		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
9-MZC	6.00		0.014		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
10-NHZ	0.03	0.03		0.043	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
11-NMI	0.15	0.15		0.028	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
12-NMA	0.13	0.13		0.026	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
13-NDT	164.00	1.64		0.059	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
14-NHP	0.33	0.33		0.028	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
15-BRD	0.51			0.058	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
16-DET	55.76/74.77							

Table S6 (continued): FWM inputs for the central basin

Input	Biomass kJ m^{-2}	Landings kJ m^{-2} d^{-1}	P/B d^{-1}	Q/B d^{-1}	AE	R	GE	EE
1-PHP	2.99/3.91		2.08			0.3–0.5	0.1–0.5	0.0–0.95
2-PHB	2476.4		0.003			0.3–0.5	0.1–0.5	0.0–0.95
3-ZOP	59		0.013		0.5–0–9	0.3–0.5	0.1–0.5	0.0–0.95
4-MEI	21.77			0.19	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
5-MDT	21.36		0.02		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
6-MHR	45.14		0.02		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
7-MFF	16.61		0.013		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
8-MMF	3.8		0.025		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
9-MZC	6		0.014		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
10-NHZ	0.0275	0.03		0.043	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
11-NMI	0.15	0.15		0.028	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
12-NMA	0.1281	0.13		0.026	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
13-NDT	164	1.64		0.059	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
14-NHP	0.3329	0.33		0.028	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
15-BRD	0.51			0.058	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
16-DET	60.46/75.69							

Table S6 (continued): FWM inputs for the eastern basin

Input	Biomass kJ m^{-2}	Landings kJ m^{-2} d^{-1}	P/B d^{-1}	Q/B d^{-1}	AE	R	GE	EE
1-PHP	2.28/2.66		2.08			0.3–0.5	0.1–0.5	0.0–0.95
2-PHB	2476.4		0.003			0.3–0.5	0.1–0.5	0.0–0.95
3-ZOP	80		0.013		0.5–0-9	0.3–0.5	0.1–0.5	0.0–0.95
4-MEI	21.77			0.19	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
5-MDT	18.83		0.02		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
6-MHR	39.79		0.02		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
7-MFF	14.65		0.013		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
8-MMF	3.35		0.025		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
9-MZC	4		0.014		0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
10-NHZ	0.0275	0.03		0.043	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
11-NMI	0.15	0.15		0.028	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
12-NMA	0.1281	0.13		0.026	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
13-NDT	164	1.64		0.059	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
14-NHP	0.3329	0.33		0.028	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
15-BRD	0.51			0.058	0.7–0.9	0.3–0.5	0.1–0.5	0.0–0.95
16-DET	31.13/39.28							

Table S7: FWM estimated flows (kJ m^{-2} d^{-1}) for the western basin in the 'no aquaculture' (NA) scenario; see main text, Table 2, for descriptions of the ecological compartments abbreviated here in column one

	Net production	Consumption	Assimilation	Faeces	Respiration	Predation	Natural mortality	Export and catches	Input
PHP	5.94E+00					1.06E+00	8.41E-01		
PHB	7.43E+00					7.43E+00	1.06E+00		
ZOP	1.38E+00	3.31E+00	2.98E+00	3.31E-01	1.60E+00	1.32E+00	6.92E-02		
MEI	2.07E+00	4.14E+00	3.72E+00	4.14E-01	1.65E+00	1.96E+00	1.03E-01		
MDT	6.14E-01	1.23E+00	1.11E+00	1.23E-01	4.92E-01	4.55E-01	1.59E-01		
MHR	1.30E+00	1.37E+00	3.07E+00	3.41E-01	1.77E+00	7.74E-01	3.34E-01		
MFF	3.11E-01	3.11E+00	2.80E+00	3.11E-01	2.48E+00	4.61E-02	7.26E-02		
MMF	1.37E-01	1.37E+00	1.23E+00	1.37E-01	1.09E+00	7.74E-01	1.37E-01		
MZC	8.40E-02	8.40E-01	7.56E-01	8.40E-02	6.72E-01	7.98E-02	4.20E-03		
NHZ	5.91E-02	1.18E-01	1.06E-01	1.18E-02	4.73E-02	2.62E-02	2.96E-03	3.00E-02	
NMI	2.10E-01	4.20E-01	3.78E-01	4.20E-02	1.68E-01	4.95E-02	1.05E-02	1.50E-01	
NMA	1.67E-01	3.33E-01	3.00E-01	3.33E-02	4.73E-02	2.82E-02	8.33E-03	1.30E-01	
NDT	2.34E+00	4.68E+00	4.21E+00	4.68E-01	1.87E+00	5.84E-01	1.17E-01	1.64E+00	
NHP	3.63E-01	7.25E-01	6.53E-01	7.25E-02	2.90E-01	1.45E-02	1.17E-01	3.30E-01	
BRD	7.23E-03	7.23E-02	6.50E-02	7.23E-03	5.78E-02		3.61E-04	6.87E-03	
DET						7.91E+00		1.352708551	2.6

Table S7 (continued): FWM estimated flows (kJ m^{-2} d^{-1}) for the western basin in the 'aquaculture' (A) scenario

	Net production	Consumption	Assimilation	Faeces	Respiration	Predation	Natural mortality	Export and catches	Input
PHP	8.63E+00					1.03E+00	1.57E+00		
PHB	7.43E+00					7.43E+00	1.03E+00		
ZOP	1.41E+00	4.53E+00	4.08E+00	4.53E-01	2.67E+00	1.34E+00	7.03E-02		
MEI	2.07E+00	4.14E+00	3.72E+00	4.14E-01	1.65E+00	1.96E+00	1.03E-01		
MDT	6.14E-01	1.26E+00	1.14E+00	1.26E-01	5.24E-01	4.60E-01	1.55E-01		
MHR	1.30E+00	1.37E+00	3.79E+00	4.21E-01	2.49E+00	7.61E-01	3.29E-01		
MFF	3.11E-01	3.11E+00	2.80E+00	3.11E-01	2.48E+00	4.61E-02	6.96E-02		
MMF	1.37E-01	1.37E+00	1.23E+00	1.37E-01	1.09E+00	7.61E-01	1.37E-01		
MZC	8.40E-02	8.40E-01	7.56E-01	8.40E-02	6.72E-01	7.98E-02	4.20E-03		
NHZ	5.91E-02	1.18E-01	1.06E-01	1.18E-02	4.73E-02	2.62E-02	2.96E-03	3.00E-02	
NMI	2.10E-01	4.20E-01	3.78E-01	4.20E-02	1.68E-01	4.95E-02	1.05E-02	1.50E-01	
NMA	1.67E-01	3.33E-01	3.00E-01	3.33E-02	4.73E-02	2.82E-02	8.33E-03	1.30E-01	
NDT	2.34E+00	4.68E+00	4.21E+00	4.68E-01	1.87E+00	5.84E-01	1.17E-01	1.64E+00	
NHP	3.63E-01	7.25E-01	6.53E-01	7.25E-02	2.90E-01	1.45E-02	1.17E-01	3.30E-01	
BRD	7.23E-03	7.23E-02	6.50E-02	7.23E-03	5.78E-02		3.61E-04	6.87E-03	
DET						8.81E+00		2.221025364	2.6

Table S7 (continued): FWM estimated flows (kJ m^{-2} d^{-1}) for the central basin in the 'no aquaculture' (NA) scenario

	Net production	Consumption	Assimilation	Faeces	Respiration	Predation	Natural mortality	Export and catches	Input
PHP	5.53E+00					1.40E+00	1.71E+00		
PHB	7.43E+00					7.43E+00	1.40E+00		
ZOP	7.67E-01	1.96E+00	1.76E+00	1.96E-01	9.94E-01	7.29E-01	3.83E-02		
MEI	2.07E+00	4.14E+00	3.72E+00	4.14E-01	1.65E+00	1.96E+00	1.03E-01		
MDT	4.27E-01	9.59E-01	8.64E-01	9.59E-02	4.36E-01	3.70E-01	5.71E-02		
MHR	9.03E-01	9.50E-01	3.68E+00	4.08E-01	2.77E+00	7.60E-01	1.83E-01		
MFF	2.16E-01	2.16E+00	1.94E+00	2.16E-01	1.73E+00	8.17E-02	1.08E-02		
MMF	9.50E-02	9.50E-01	8.55E-01	9.50E-02	7.60E-01	7.60E-01	9.50E-02		
MZC	8.40E-02	8.40E-01	7.56E-01	8.40E-02	6.72E-01	7.98E-02	4.20E-03		
NHZ	5.91E-02	1.18E-01	1.06E-01	1.18E-02	4.73E-02	2.62E-02	2.96E-03	3.00E-02	
NMI	2.10E-01	4.20E-01	3.78E-01	4.20E-02	1.68E-01	4.95E-02	1.05E-02	1.50E-01	
NMA	1.67E-01	3.33E-01	3.00E-01	3.33E-02	4.73E-02	2.82E-02	8.33E-03	1.30E-01	
NDT	2.31E+00	4.62E+00	4.16E+00	4.62E-01	1.85E+00	5.55E-01	1.16E-01	1.64E+00	
NHP	3.54E-01	7.07E-01	6.36E-01	7.07E-02	2.83E-01	5.92E-03	1.16E-01	3.30E-01	
BRD	2.96E-03	2.96E-02	2.66E-02	2.96E-03	2.37E-02		1.48E-04	2.81E-03	
DET						8.50E+00		1.757032334	2.6

Table S7 (continued): FWM estimated flows (kJ m^{-2} d^{-1}) for the central basin in the 'aquaculture' (A) scenario

	Net production	Consumption	Assimilation	Faeces	Respiration	Predation	Natural mortality	Export and catches	Input
PHP	7.23E+00					1.36E+00	2.65E+00		
PHB	7.43E+00					7.43E+00	1.36E+00		
ZOP	7.67E-01	1.96E+00	1.76E+00	1.96E-01	9.94E-01	7.29E-01	3.83E-02		
MEI	2.07E+00	4.14E+00	3.72E+00	4.14E-01	1.65E+00	1.96E+00	1.03E-01		
MDT	4.27E-01	1.29E+00	1.16E+00	1.29E-01	7.35E-01	3.70E-01	5.71E-02		
MHR	9.03E-01	9.50E-01	4.40E+00	4.89E-01	3.50E+00	7.60E-01	1.83E-01		
MFF	2.16E-01	2.16E+00	1.94E+00	2.16E-01	1.73E+00	8.17E-02	1.08E-02		
MMF	9.50E-02	9.50E-01	8.55E-01	9.50E-02	7.60E-01	7.60E-01	9.50E-02		
MZC	8.40E-02	8.40E-01	7.56E-01	8.40E-02	6.72E-01	7.98E-02	4.20E-03		
NHZ	5.91E-02	1.18E-01	1.06E-01	1.18E-02	4.73E-02	2.62E-02	2.96E-03	3.00E-02	
NMI	2.10E-01	4.20E-01	3.78E-01	4.20E-02	1.68E-01	4.95E-02	1.05E-02	1.50E-01	
NMA	1.67E-01	3.33E-01	3.00E-01	3.33E-02	4.73E-02	2.82E-02	8.33E-03	1.30E-01	
NDT	2.31E+00	4.62E+00	4.16E+00	4.62E-01	1.85E+00	5.55E-01	1.16E-01	1.64E+00	
NHP	3.54E-01	7.07E-01	6.36E-01	7.07E-02	2.83E-01	5.92E-03	1.16E-01	3.30E-01	
BRD	2.96E-03	2.96E-02	2.66E-02	2.96E-03	2.37E-02		1.48E-04	2.81E-03	
DET						9.50E+00		2.433178068	2.6

Table S7 (continued): FWM estimated flows (kJ m^{-2} d^{-1}) for the eastern basin in the 'no aquaculture' (NA) scenario

	Net production	Consumption	Assimilation	Faeces	Respiration	Predation	Natural mortality	Export and catches	Input
PHP	4.74E+00					1.19E+00	5.89E-01		
PHB	7.43E+00					7.43E+00	1.19E+00		
ZOP	1.04E+00	3.35E+00	3.01E+00	3.35E-01	1.97E+00	9.88E-01	5.20E-02		
MEI	2.07E+00	4.14E+00	3.72E+00	4.14E-01	1.65E+00	1.96E+00	1.03E-01		
MDT	3.77E-01	1.08E+00	9.75E-01	1.08E-01	5.98E-01	1.54E-01	2.22E-01		
MHR	7.96E-01	8.38E-01	3.23E+00	3.59E-01	2.44E+00	6.70E-01	3.87E-01		
MFF	1.90E-01	1.90E+00	1.71E+00	1.90E-01	1.52E+00	1.05E-02	1.39E-01		
MMF	8.38E-02	8.38E-01	7.54E-01	8.38E-02	6.70E-01	6.70E-01	8.37E-02		
MZC	5.60E-02	1.38E-01	1.24E-01	1.38E-02	6.82E-02	5.32E-02	2.80E-03		
NHZ	5.91E-02	1.18E-01	1.06E-01	1.18E-02	4.73E-02	2.62E-02	2.96E-03	3.00E-02	
NMI	2.10E-01	4.20E-01	3.78E-01	4.20E-02	1.68E-01	4.95E-02	1.05E-02	1.50E-01	
NMA	1.67E-01	3.33E-01	3.00E-01	3.33E-02	4.73E-02	2.82E-02	8.33E-03	1.30E-01	
NDT	2.32E+00	4.65E+00	4.18E+00	4.65E-01	1.86E+00	5.67E-01	1.16E-01	1.64E+00	
NHP	3.54E-01	7.07E-01	6.36E-01	7.07E-02	2.83E-01	5.92E-03	1.16E-01	3.30E-01	
BRD	2.96E-03	2.96E-02	2.66E-02	2.96E-03	2.37E-02		1.48E-04	2.81E-03	
DET						8.66E+00		2.051185826	3.6

Table S7 (continued): FWM estimated flows (kJ m^{-2} d^{-1}) for the eastern basin in the 'aquaculture' (A) scenario

	Net production	Consumption	Assimilation	Faeces	Respiration	Predation	Natural mortality	Export and catches	Input
PHP	5.53E+00					1.20E+00	8.14E-01		
PHB	7.43E+00					7.43E+00	1.20E+00		
ZOP	1.04E+00	3.69E+00	3.32E+00	3.69E-01	2.28E+00	9.88E-01	5.20E-02		
MEI	2.07E+00	4.14E+00	3.72E+00	4.14E-01	1.65E+00	1.96E+00	1.03E-01		
MDT	3.77E-01	1.18E+00	1.06E+00	1.18E-01	6.83E-01	1.54E-01	2.22E-01		
MHR	7.96E-01	8.38E-01	3.43E+00	3.81E-01	2.64E+00	6.70E-01	3.87E-01		
MFF	1.90E-01	1.90E+00	1.71E+00	1.90E-01	1.52E+00	1.05E-02	1.39E-01		
MMF	8.37E-02	8.38E-01	7.54E-01	8.38E-02	6.70E-01	6.70E-01	8.38E-02		
MZC	5.60E-02	1.38E-01	1.24E-01	1.38E-02	6.82E-02	5.32E-02	2.80E-03		
NHZ	5.91E-02	1.18E-01	1.06E-01	1.18E-02	4.73E-02	2.62E-02	2.96E-03	3.00E-02	
NMI	2.10E-01	4.20E-01	3.78E-01	4.20E-02	1.68E-01	4.95E-02	1.05E-02	1.50E-01	
NMA	1.67E-01	3.33E-01	3.00E-01	3.33E-02	4.73E-02	2.82E-02	8.33E-03	1.30E-01	
NDT	2.32E+00	4.65E+00	4.18E+00	4.65E-01	1.86E+00	5.67E-01	1.16E-01	1.64E+00	
NHP	3.54E-01	7.07E-01	6.36E-01	7.07E-02	2.83E-01	5.92E-03	1.16E-01	3.30E-01	
BRD	2.96E-03	2.96E-02	2.66E-02	2.96E-03	2.37E-02		1.48E-04	2.81E-03	
DET						8.95E+00		2.247092769	3.6

References

Ciavatta S, Pastres R, Badetti C, Ferrari G, Beck MB. 2008. Estimation of phytoplanktonic production and system respiration from data collected by a real-time monitoring network in the Lagoon of Venice. *Ecological Modelling* 212: 28–36.

Finn JT. 1976. Measures of ecosystem structure and function derived from analysis of flows. *Journal of Theoretical Biology* 56: 363–380.

Lovato T, Ciavatta S, Brigolin D, Rubino A, Pastres R. 2013. Modelling dissolved oxygen and benthic-algae dynamics in a coastal ecosystem by exploiting real-time monitoring data. *Estuarine, Coastal and Shelf Science* 119: 17–30.

Okbah MA. 2005. Nitrogen and phosphorus species of Lake Burullus water (Egypt). *Egyptian Journal of Aquatic Research* 31: 186–198.

Pastres R, Solidoro C, Cossarini G, Melaku Canu D, Dejak C. 2001. Managing the rearing of *Tapes phillipinarum* in the Lagoon of Venice: a decision-support system. *Ecological Modelling* 138: 231–245.

Sakshaug E, Andresen K. 1986. Effect of light regime upon growth rate and chemical composition of a clone of *Skeletonema costatum* from the Trondheimsfjord, Norway. *Journal of Plankton Research* 8: 619–637.

Sarthou G, Timmermans KR, Blain S, Tréguer P. 2005. Growth physiology and fate of diatoms in the ocean: a review. *Journal of Sea Research* 53: 25–42.

Ulanowicz RE. 1980. A hypothesis on the development of natural communities. *Journal of Theoretical Biology* 85: 223–245.

Ulanowicz RE. 1986. A phenomenological perspective of ecological development. In: Poston TM, Purdy R (eds), *Aquatic toxicology and environmental fate*, Vol. 9, pp. 73–81. Philadelphia, Pennsylvania: American Society for Testing and Materials.

Ulanowicz RE. 2000. Ascendancy: a measure of ecosystem performance. In: Jorgensen SE, Mueller F (eds), *Handbook of ecosystem theories and management*, pp 305–315. Boca Raton, Florida: Lewis.