Application of Modified NEMURO Model to Jiaozhou Bay

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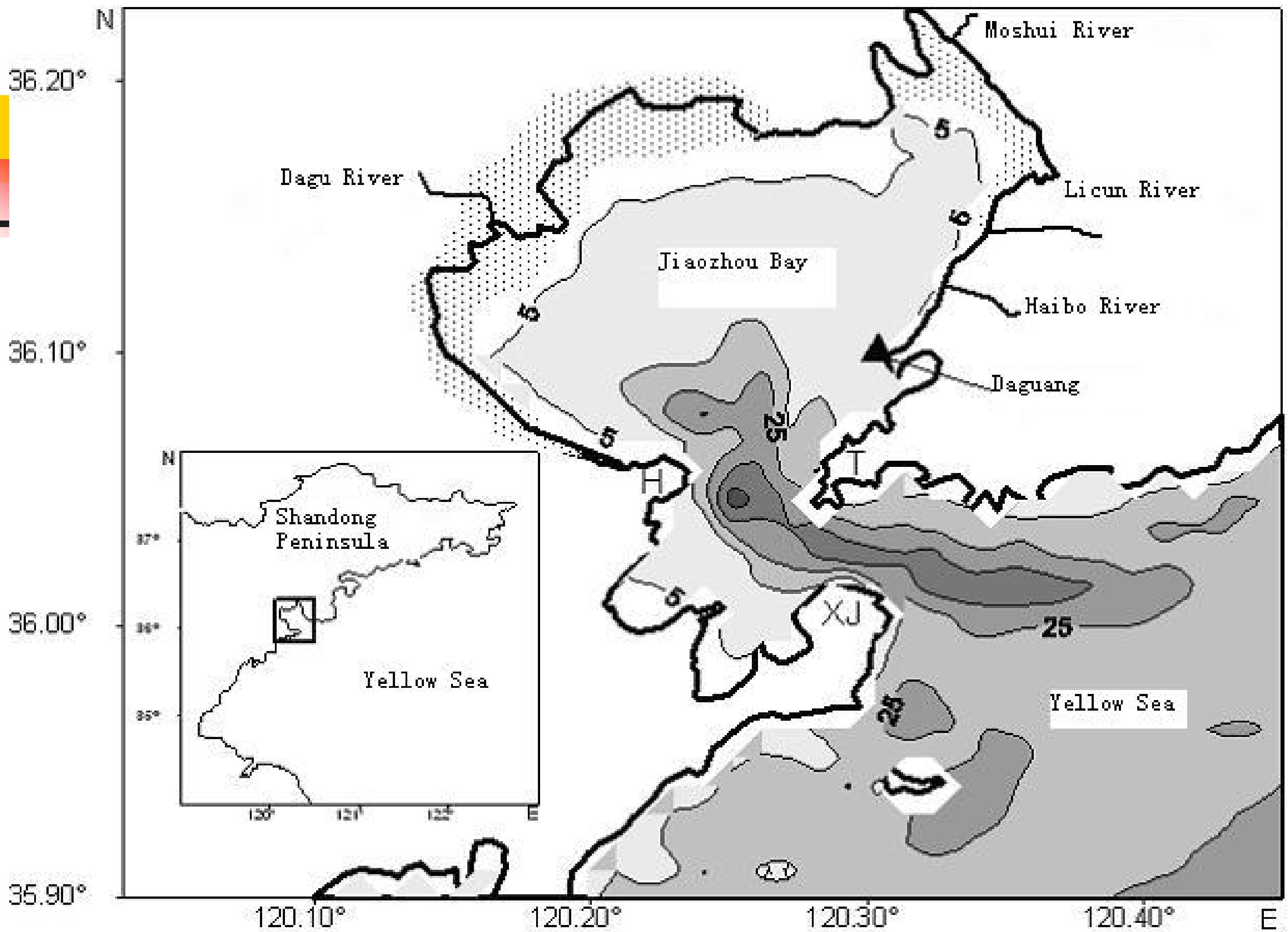
Significance of MEBM in Jiaozhou Bay

- HAB is increasing 3 times/a in China marine area. 1952~1998, 322 harmful red tides happened, and economic losses averages to 1 billion one year.
  Zhou Mingjiang *et al*. (2001)

- Eutrophication is aggravated in Jiaozhou Bay in 1990s. Red tides happened 4 times in the summer 1999. Environment Protection Agency of Qingdao (1999)



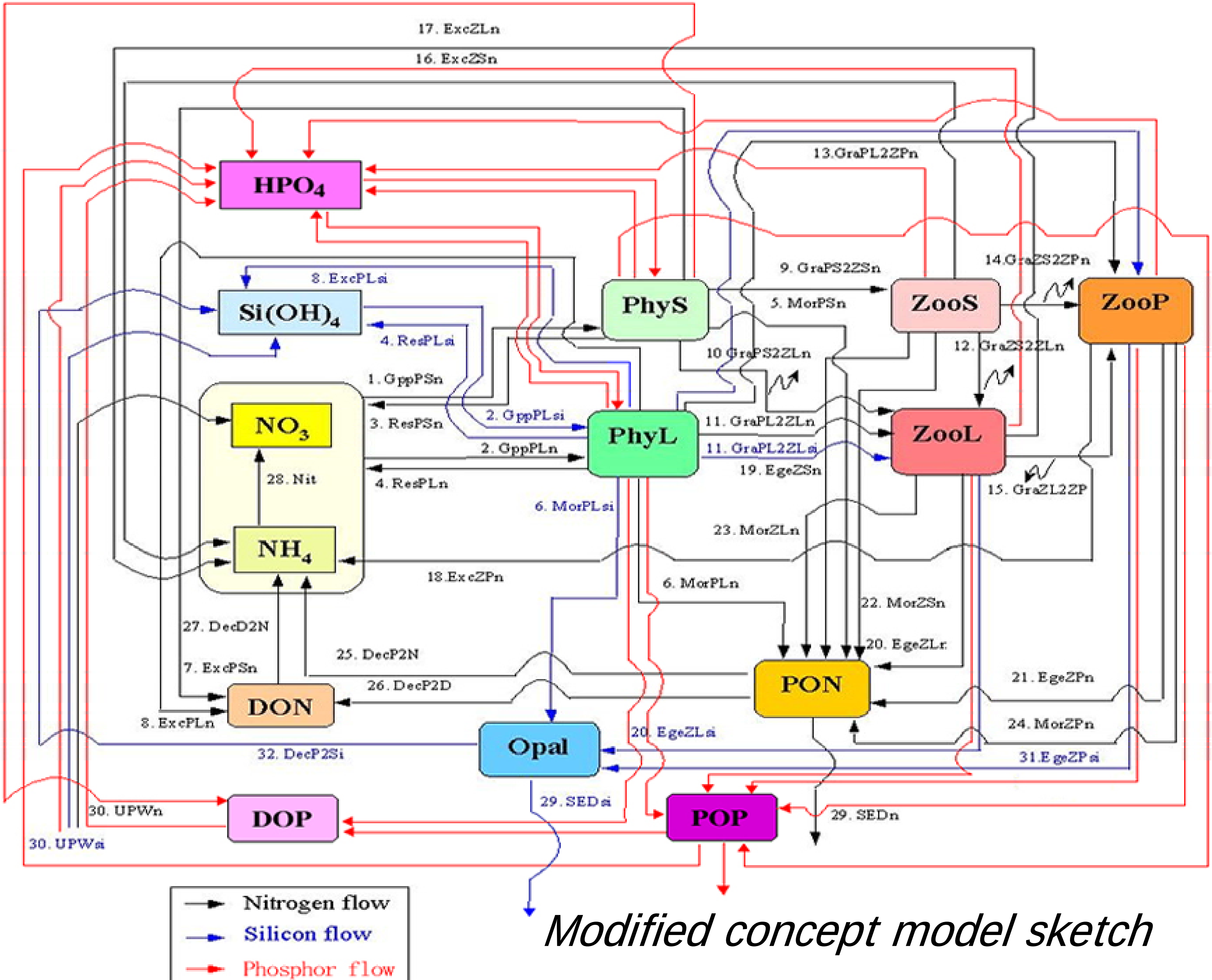
Jiaozhou Bay: abutting to Yellow Sea, 390km^2 totally and 6.8 m depth average.

Nutrient Changes in Jiaozhou Bay

- DIN was often run out during blooms in 1960s, so nitrate is limit nutrient. Gu Hongkan (1982)
- Atomic ratio of DIN:HPO_4 increased from 15.9 ± 6.3 for 1960s, to 37.8 ± 22.9 for 1990s. DIN and HPO_4 increased 3.9 times and 1.4 times respectively, while $Si(OH)_4$ remained at a low level from 1980s to 1990s. The reasons are river pollution and decrease of silt from runoff. Z.-L. Shen (2002)
- Atomic ratio of N/P was much bigger than 16:1 all the year 1995, except for the situation in summer. Wu Zengmao *et al*. (1995)

Modified NEMURO Model

- Phosphor is considered as HPO_4, DOP and POP are new variables.
- Vertical migration of ZL is omitted.
- Changeless mixed layer depth 6m and exchange rate $1.0/(6.0\times 86400)s^{-1}$.
- Nutrients from rivers discharge and atmosphere sediment are considered together with those upwelling from bottom, in parameter UPW.
- HPO_4 takes part in formula or primary productivity as another parameter of the minimum-law.



Modified concept model sketch

Equations for Phosphor circulation

$$\frac{dPhySph}{dt} = GppPSph - \mathrm{Re}\,sPSph - MorPSph - ExcPSph - GraPS2ZSph - GraPS2ZLph$$

$$\frac{dPhyLph}{dt} = GppPLph - \mathrm{Re}\,sPLph - MorPLph - ExcPLph - GraPL2ZLph - GraPL2ZPph$$

$$\frac{dZooSph}{dt} = GraPS2ZSph - GraZS2ZLph - GraZS2ZPph - MorZSph - ExcZSph - EgeZSph$$

$$\frac{dZooLph}{dt} = GraPS2ZLph + GraPL2ZLph + GraZS2ZLph - GraZL2ZPph - MorZLph - ExcZLph - EgeZLph$$

$$\frac{dZooPph}{dt} = GraPL2ZPph + GraZS2ZPph + GraZL2ZPph - MorZPph - ExcZPph - EgeZPph$$

$$\frac{dHPO4}{dt} = -GppPSph - GppPLph + \mathrm{Re}\,sPSph + \mathrm{Re}\,sPLph + DecP2PHph + DecD2PHph + ExcZSph + ExcZLph$$
$$+ ExcZPph + UPWph$$

$$\frac{dDOP}{dt} = ExcPSph + ExcPLph + DecP2Dph - DecD2PHph$$

$$\frac{dPOP}{dt} = MorPSph + MorPLph + MorZSph + MorZLph + MorZPph + EgeZSph + EgeZLph + EgeZPph$$
$$- DecP2Dph - DecP2PHph - SEDph$$

Phosphor in Nutrients Limit

$$GppPSn = V\max S \times \min\left(\frac{NO3}{NO3+KNO3S}\exp(-\phi \times NH4) + \frac{NH4}{NH4+KNH4S}, \frac{HPO4}{HPO4+KHPO4S}\right)$$

$$\times \exp(KGpps \times TMP) \times \int_{-H}^{0} \frac{I}{IoptS}\exp\left(1-\frac{I}{IoptS}\right)dz \times PhySn$$

$$GppPLn = V\max L \times \min\left(\frac{NO3}{NO3+KNO3L}\exp(-\phi \times NH4) + \frac{NH4}{NH4+KNH4L}, \frac{Si(OH)4}{Si(OH)4+KSiL}, \frac{HPO4}{HPO4+KHPO4L}\right)$$

$$\times \exp(KGppl \times TMP) \times \int_{-H}^{0} \frac{I}{IoptL}\exp\left(1-\frac{I}{IoptL}\right)dz \times PhyLn$$

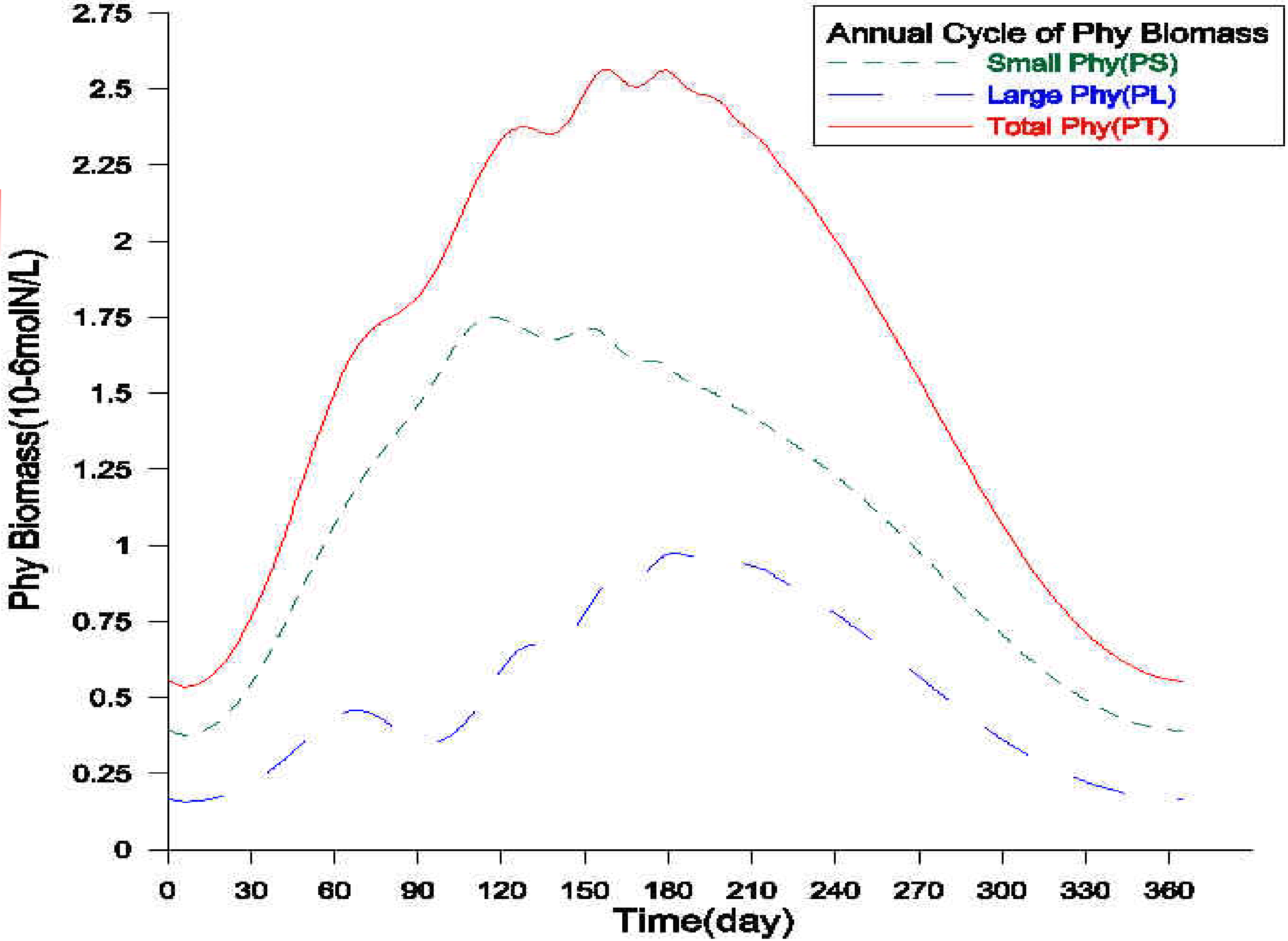
Parameters	Introduction	Value	Unit
VmaxS	Max photosynthesis rate at 0• € by PhyS	1.0	day^{-1}
VmaxL	Max photosynthesis at 0• € by PhyL	2.0	day^{-1}
Iopt	Light intensity of optimum photosynthesis by PhyS and PhyL	0.15	ly/min
KGpp	Temperature coefficient for photosynthesis by PhyS and PhyL	6.93×10^{-2}	$degC^{-1}$
KNO3S	PS Half saturation constant for Nitrate to PS	1.0×10^{-6}	molN/L
KNH4S	PS Half saturation constant for Ammonium to PS	0.1×10^{-6}	molN/L
KNO3L	PL Half saturation constant for Nitrate to PL	3.0×10^{-6}	molN/L
KNH4L	PL Half saturation constant for Ammonium to PL	0.3×10^{-6}	molN/L
KHPO4	PS Half saturation constant for Phosphor to PS and PL	0.815×10^{-6}	molPh/L
KSiL	PL Half saturation constant for Silicate to PL	6.0×10^{-6}	molSi/L
ExcTime	Exch. Coefficient. between all interfaces	$1.0/(6.0 \times 86400)$	s^{-1}
MLD	Mixed layer depth	6.0	m
TNO3d	NO3 concentration out of MLD	14.0×10^{-6}	molN/L
TSiOH4d	SiOH4 concentration out of MLD	10.0×10^{-6}	molSi/L
THPO4d	HPO4 concentration out of MLD	1.0×10^{-6}	molPh/L

Physical forcing functions of temperature and light intensity

- Simulating dates from May 15th 1991 to Feb 15th 1998 by annual cycle with seasonal variation of light and temperature factors.
- Trigonometric function fitted by daily-averaged light intensity data in 1995, and spline function by month-averaged temperature data rectified from that at Tianjin for years. Wu zengmao, 1999

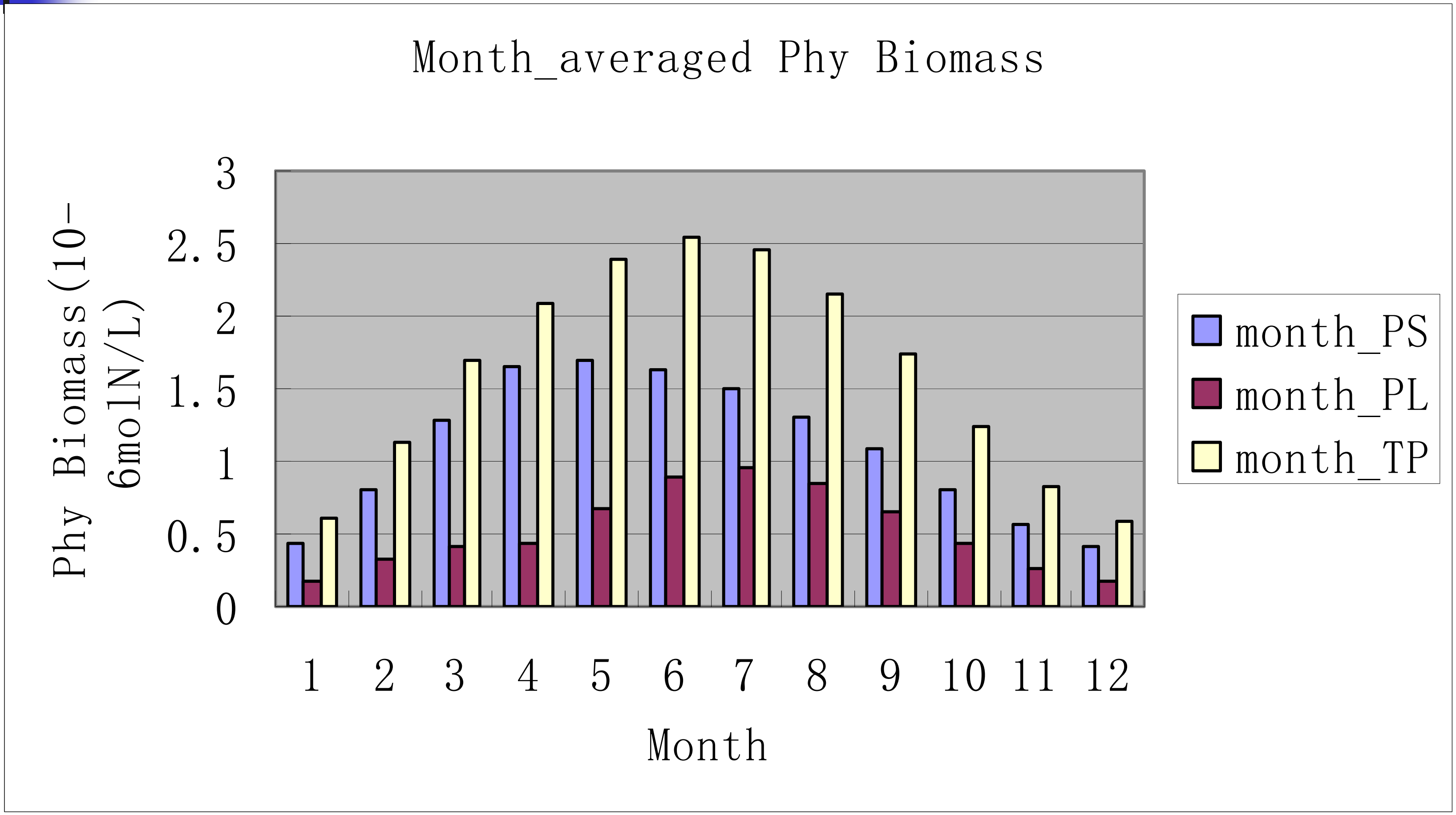
$$L\text{int}0 = 1.09 \times [0.4451 \times t^4 - 0.7566t^3 + 0.191t^2 + 0.123t + 0.02237] \qquad t \in [0,1]$$

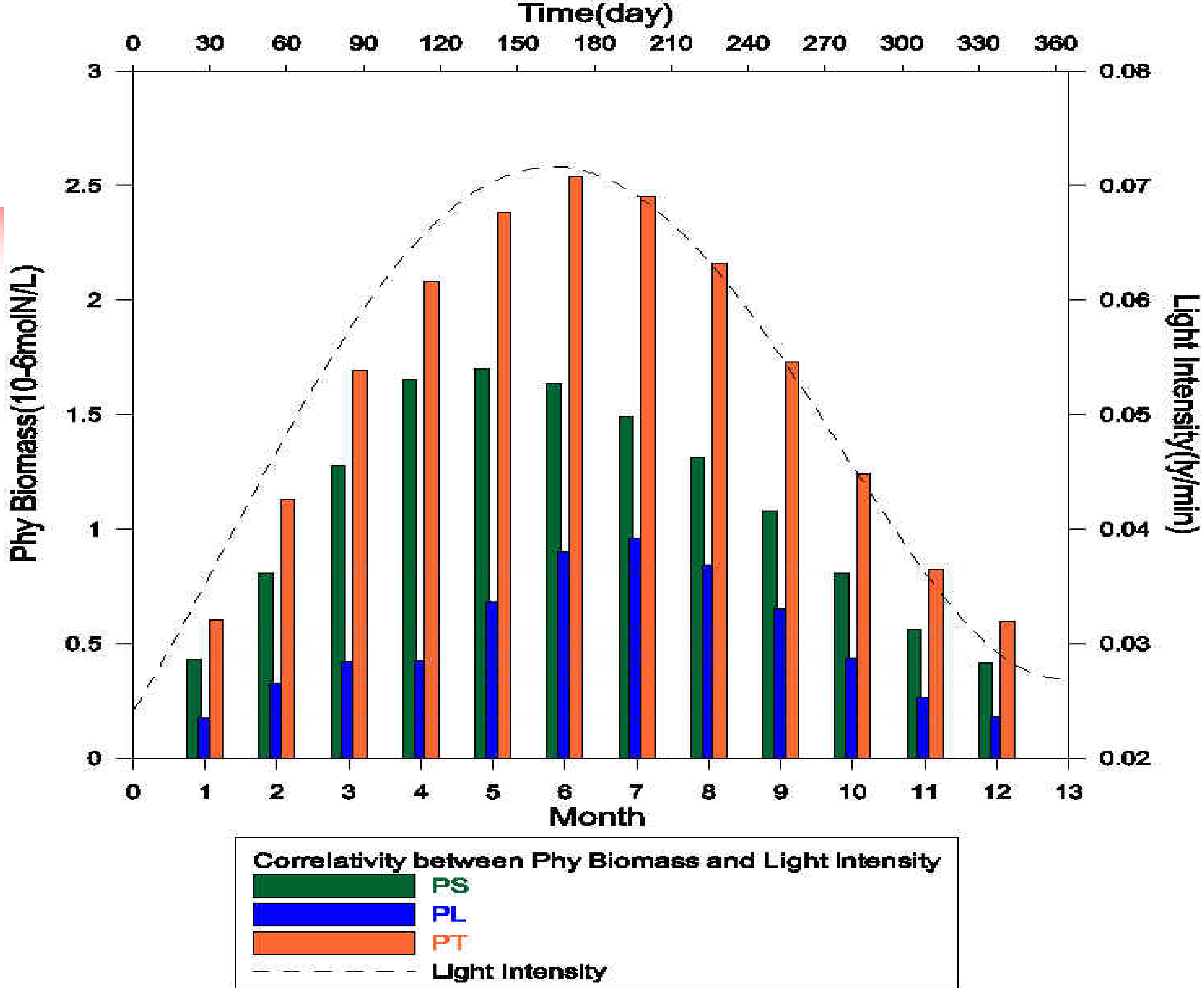
$$Temp = 14.19 - 8.79 \times \cos(5.932 \times t) - 8.12 \times \sin(5.932 \times t) \qquad t \in [0,1]$$

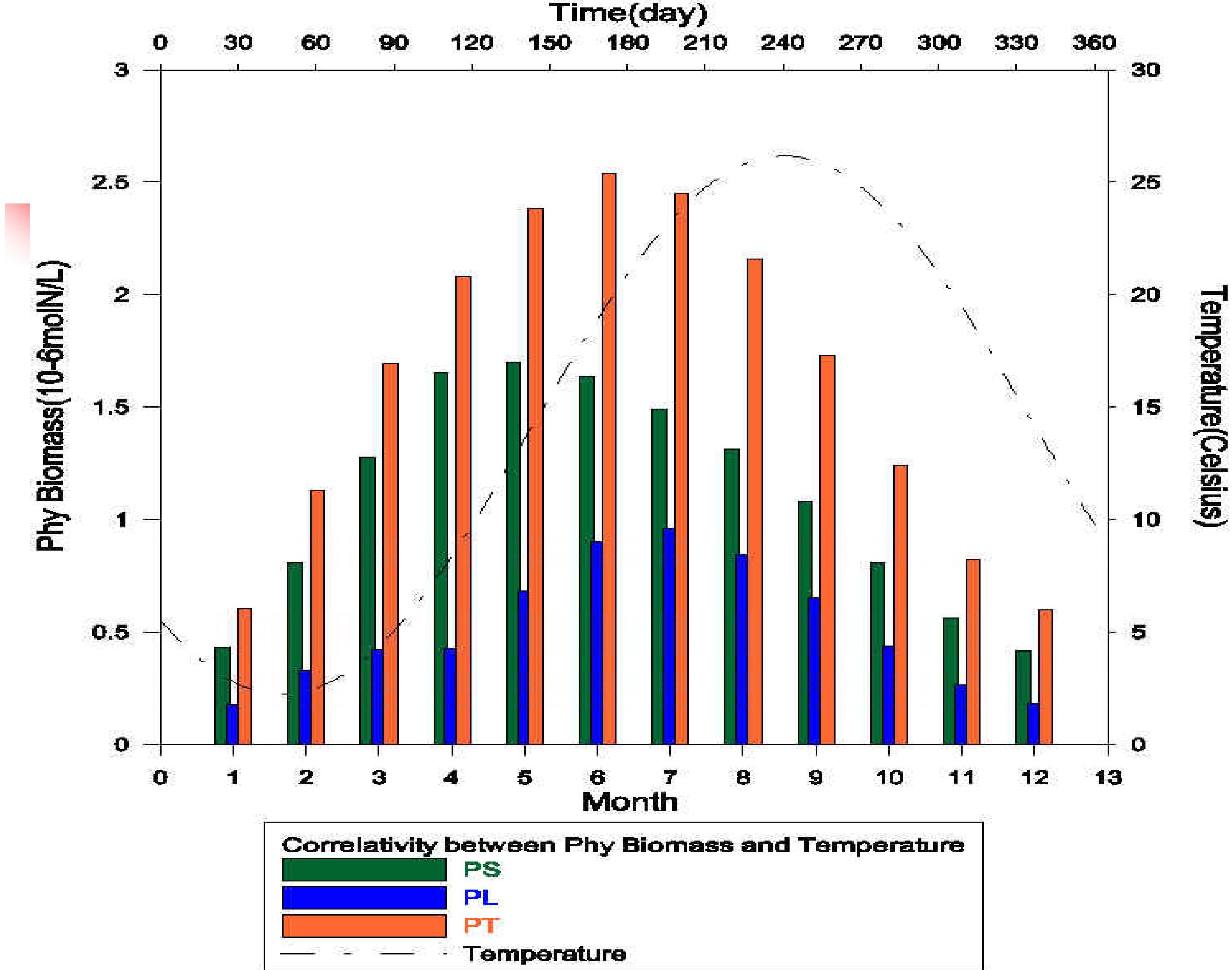


Annual cycle of Phy Biomass

Annual cycle of Phy Biomass




Time(day)
0 30 60 90 120 150 180 210 240 270 300 330 360
Phy Biomass(10-6molN/L)
0 0.5 1 1.5 2 2.5 3
Light Intensity(ly/min)
0.02 0.03 0.04 0.05 0.06 0.07 0.08
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Month
Correlativity between Phy Biomass and Light Intensity
PS
PL
PT
Light Intensity



Time(day)
0
30
60
90
120
150
180
210
240
270
300
330
360
Phy Biomass(10-6molN/L)
Temperature(Celsius)
Month
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Correlativity between Phy Biomass and Temperature
PS
PL
PT
Temperature

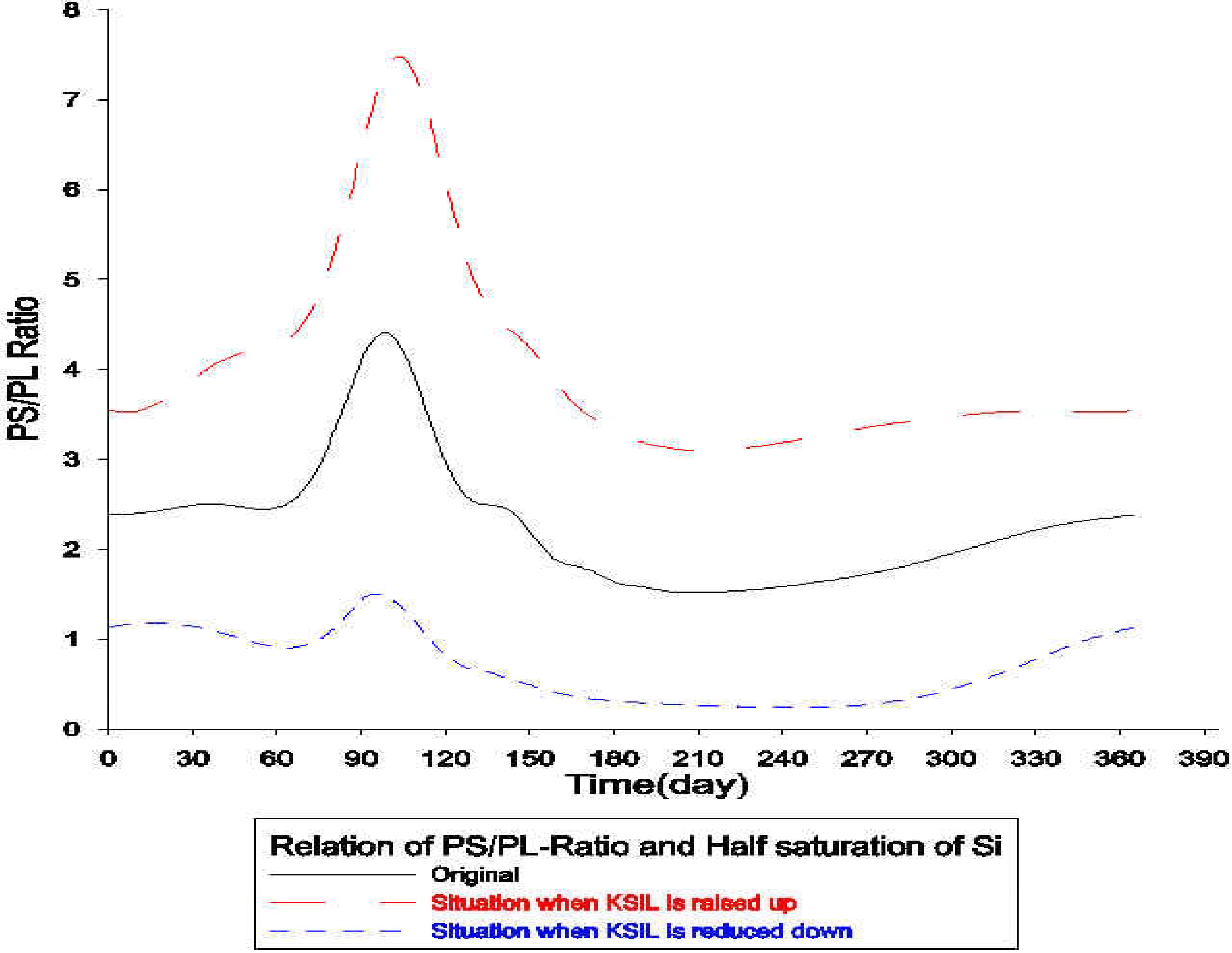
Sensitivity analysis

- Focusing on low-trophic-level, Phytoplankton-biomass-related parameters
- Maximum nutrient uptake rate
- Optimum light intensity
- Half saturation of nutrients
- Nutrients concentrations out of MLD

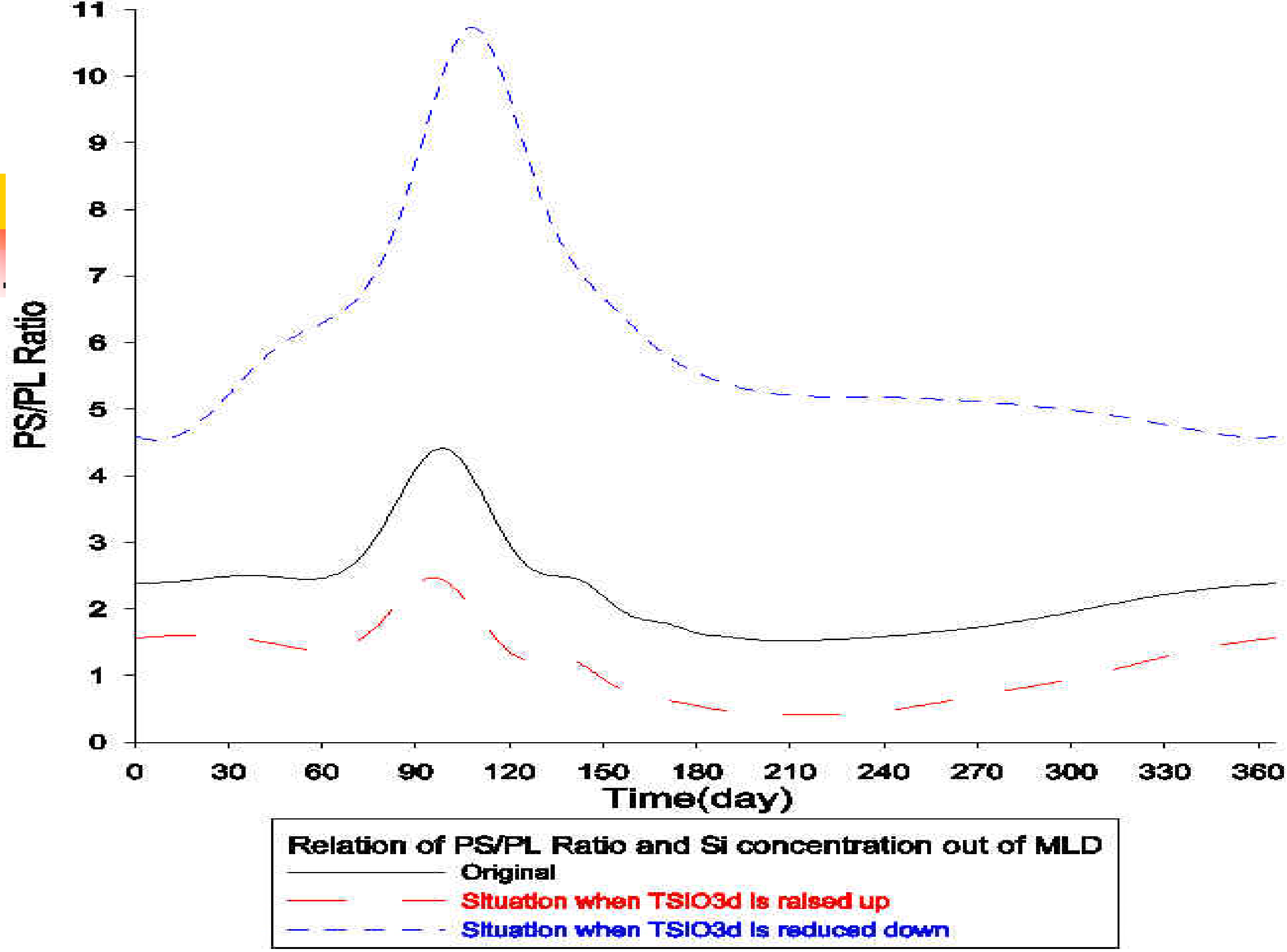
Parameter	Raised or decreased	PhyS Biomass relate change&Sensi-degree		PhyL Biomass relate change&Sensi-degree		PhyT Biomass relate change&Sensi-degree	
VmaxS	+50%	+91%	1.82	-28%	0.56	+52%	1.04
	-50%	-92%	1.84	+194%	3.88	+1.5%	0.03
VmaxL	+50%	-51%	1.02	478%	9.56	120%	2.4
	-50%	-10%	0.2	-84%	1.68	-34%	0.68
Iopt0	+20%	-22%	1.1	-31%	1.55	-25%	1.25
	-20%	+29%	1.45	+62%	3.1	+39%	1.95
KNO3S	+50%	-1%	0.02	+0.6%	0.012	-0.55%	0.011
	-50%	+1%	0.02	-0.6%	0.012	+0.48%	0.0096
KNO3L	+50%	+0.45%	0.009	-0.26%	0.0052	+0.22%	0.0044
	-50%	-0.5%	0.01	+0.3%	0.006	-0.24%	0.0048
KSiL	+50%	+2.4%	0.048	-45%	0.9	-13%	0.26
	-50%	-28%	0.56	+204%	4.1	+47%	0.94
TNO3d	+50%	+0.5%	0.01	-0.12%	0.0024	0.21%	0.0042
	-50%	-1.5%	0.03	+0.9%	0.018	-0.7%	0.014
TSiOH4d	+50%	-16%	0.32	+105%	2.1	+23%	0.46
	-50%	-0.7%	0.014	-65%	1.3	-21.6%	0.432

Relate change = $\frac{\Delta\alpha}{\alpha}$ α ——parameter

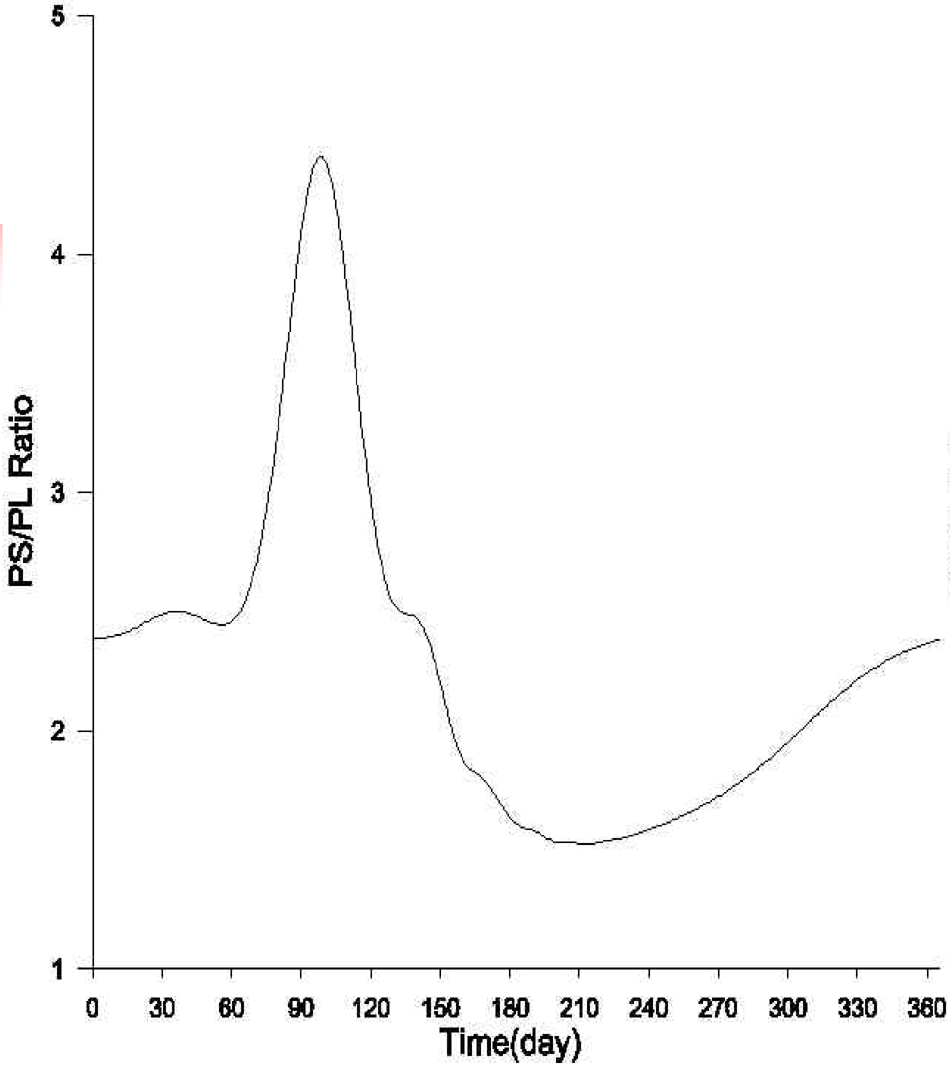
Sensi-degree(Š) = $\left|\frac{\Delta F / F}{\Delta\alpha / \alpha}\right|$ α ——parameter; F——variable

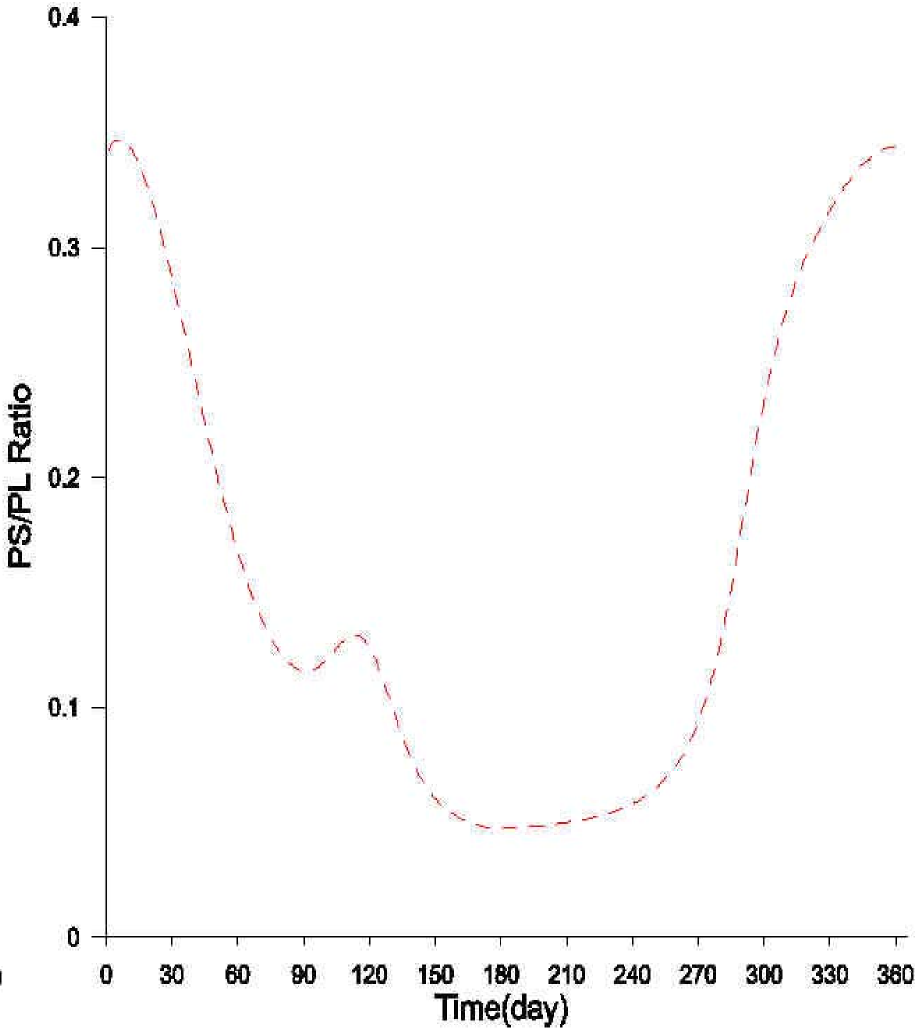


Sensitivity of Regime Composition to Si Half Saturation

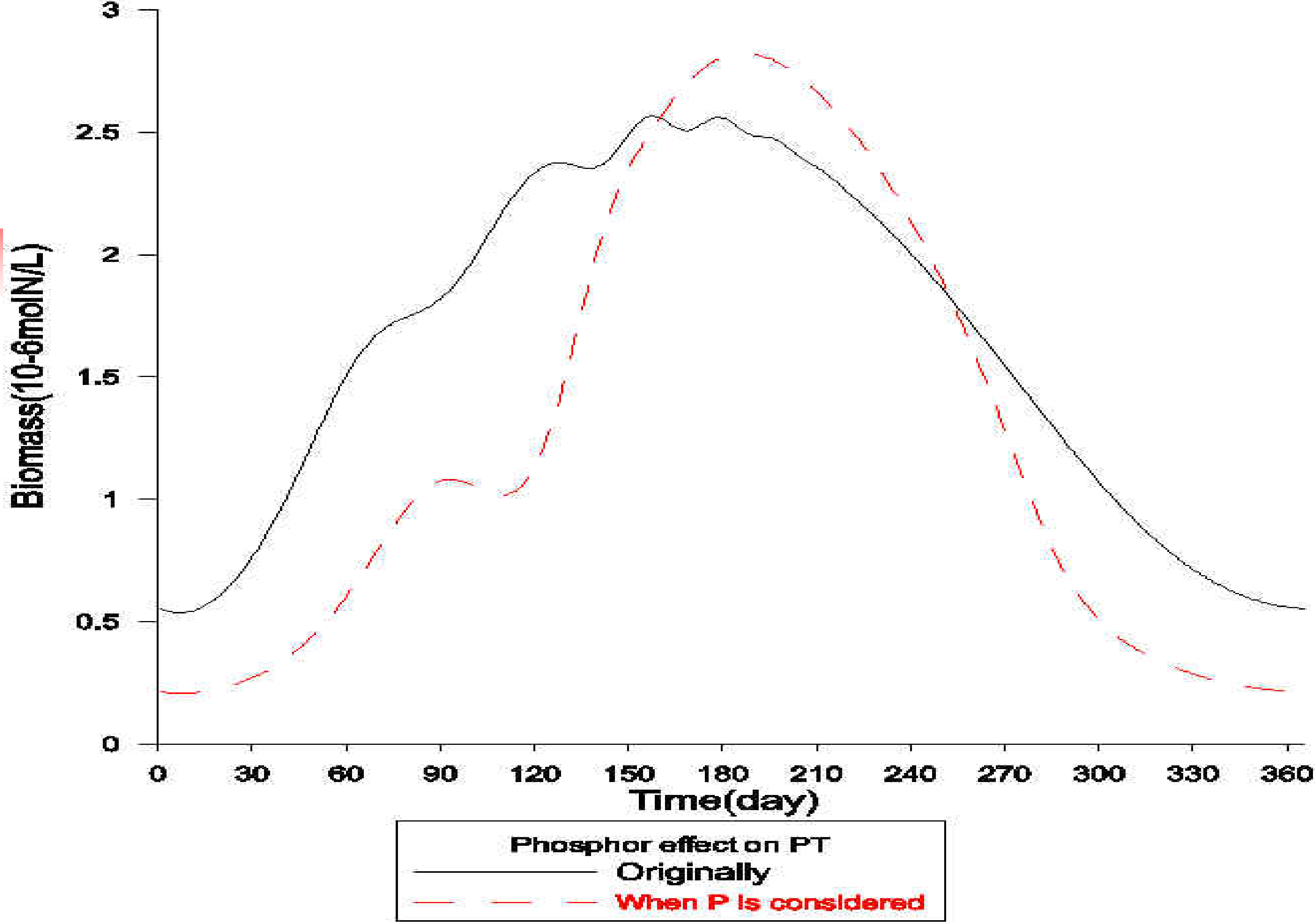


Sensitivity of PS/PL Ratio to Si concentration out of MLD





Regime Composition change brought by P considered in Model



Phosphor effect on Total Phytoplankton Biomass Annually

Sensitive analysis for phosphor-related parameters

Parameter	Raised reduced	PS change rate and Š		PL change rate and Š		PT change rate and Š		Ratio change rate and Š	
KHPO4S	+50%	-34%	0.68	+7.3%	0.146	+13%	0.26	-31.5%	0.63
	-50%	+148%	2.96	-28%	0.56	-13.6%	0.272	+85.5%	1.71
KHPO4L	+50%	+50%	1.0	-61.2%	12.24	-52.3%	1.046	+110%	2.2
	-50%	-11.5%	0.23	+36%	0.72	+32%	0.64	-65%	1.3
THPO4d	+50%	+36.6%	0.732	+26%	0.52	+27%	0.54	-41.2%	0.824
	-50%	-38%	0.76	-76%	1.52	-73.2%	1.464	42.4%	0.848

Conclusions

- Phytoplankton biomass of both kinds has one peak during a year. PS mushrooms earlier and gets peak of 1.70 μ molN/L in May, and then declines until it reaches minimum in January at 0.35 μ molN/L. PL mushrooms later and gets peak of 0.90 μ molN/L, and declines then until the minimum in early January at 0.18 μ molN/L.
- Annual phytoplankton biomass movement has remarkable correlativity with that of Light Intensity at sea surface, rather than other physical factors.
- For low-trophic-level parameters, phytoplankton biomass is sensitive to Max nutrient uptake rate, half saturations of phosphor and silicate, out-MLD concentration of silicate. Those of silicate can make regime shift in phytoplankton community. It's silicate-limit mainly, while Nitrate is no longer limit factor.

Conclusions

- Interposition of phosphor decreases biomass of PS sharply, while that of PL increases largely, so as to PS/PL ratio comes down. Total biomass of phytoplankton becomes 22% less.
- Biomass of phytoplankton are sensitive to half saturation and out-MLD concentration of phosphor, so is PS/PL ratio. However, it remains lower than 1.0 when phosphor is under consideration, although the parameters change in reasonable range.
  (Changsheng Shen *et al*, 1999)
- Reason for phosphor effect on the ratio is not clear, but way effecting on κ (attenuant coefficient) by limiting PhyS is hypothesized.

Further work

- Explore mechanism of the Model and of the ecosystem of Jiaozhou Bay, by sensitivity analysis for more parameters.
- To make clear the reason phosphor affecting on regime composition(PS/PL Ratio).
  Observation data of PAR from Jiaozhou Bay
- Multi-box model with water exchange and X-dimension model.

Thank You