Does dam construction induce harmful algal blooms?

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Backgrounds and objectives

1. Possible causes producing plankton diversity
   (1) Spatial heterogeneity (Tilman, 1982)
   "Resource supply ratio theory"

   (2) Temporal heterogeneity (Odam *et al*., 1995)
   "Pulsing paradigm"

2. Estuaries, most heterogeneous sites

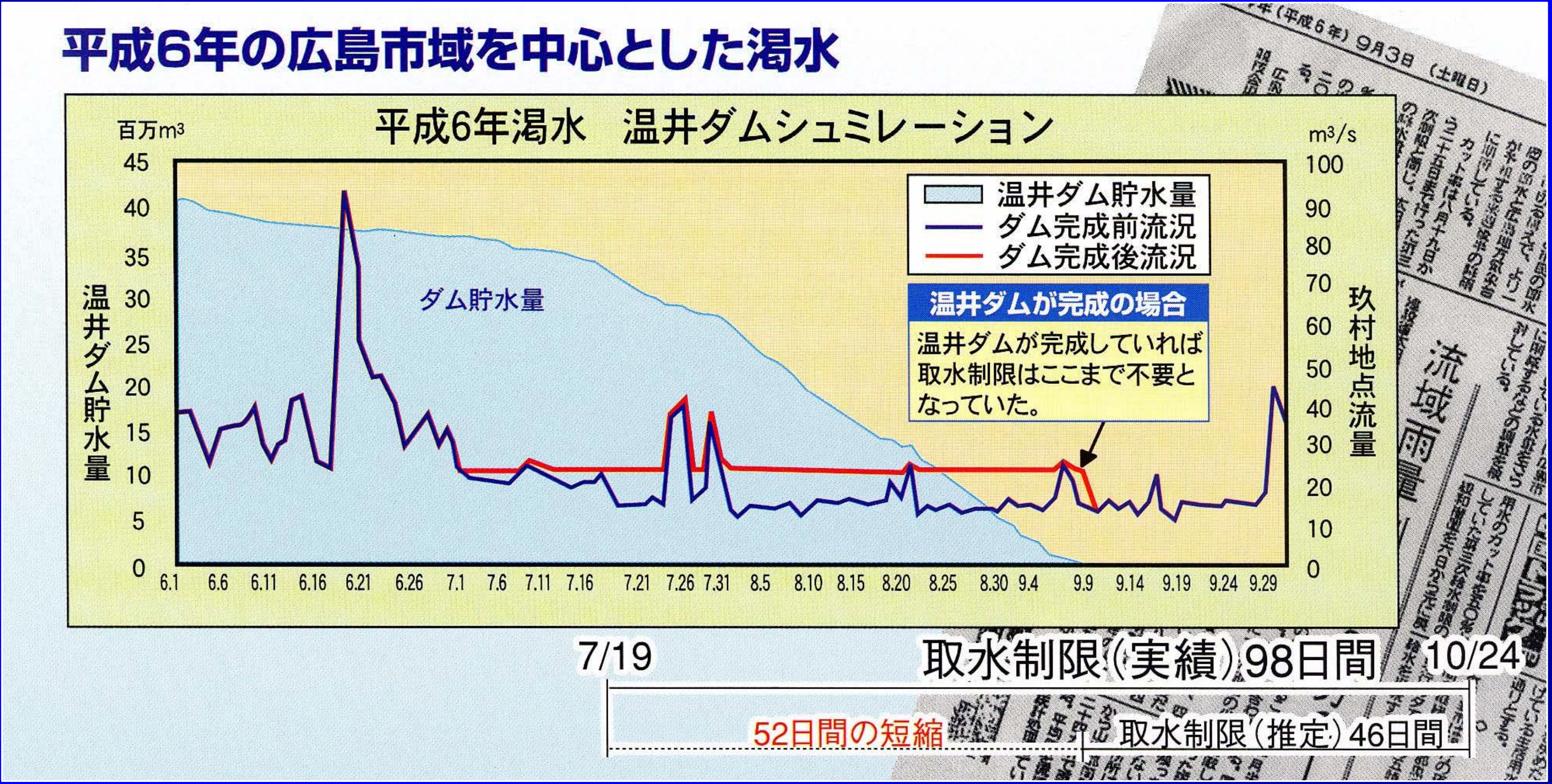
3. Dam constructions at the upper river

4. Numerical model: IBM (species competition model) to investigate if dam constructions could induce HABs

五風十雨 “Go-fu, Ju-u”

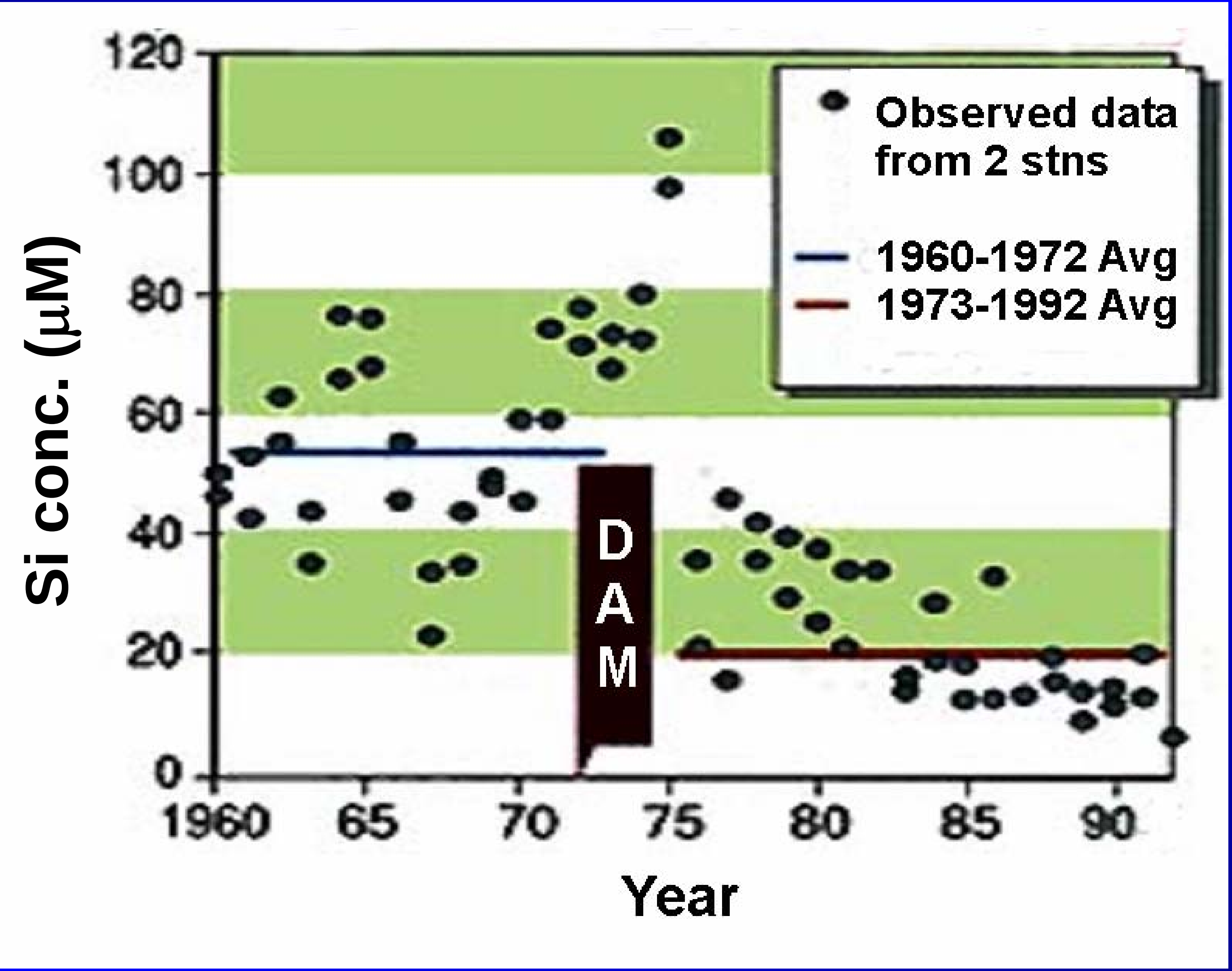
One windy day at every five days and one rainy day at every ten days

Typical peaceful normal weather condition in Japan

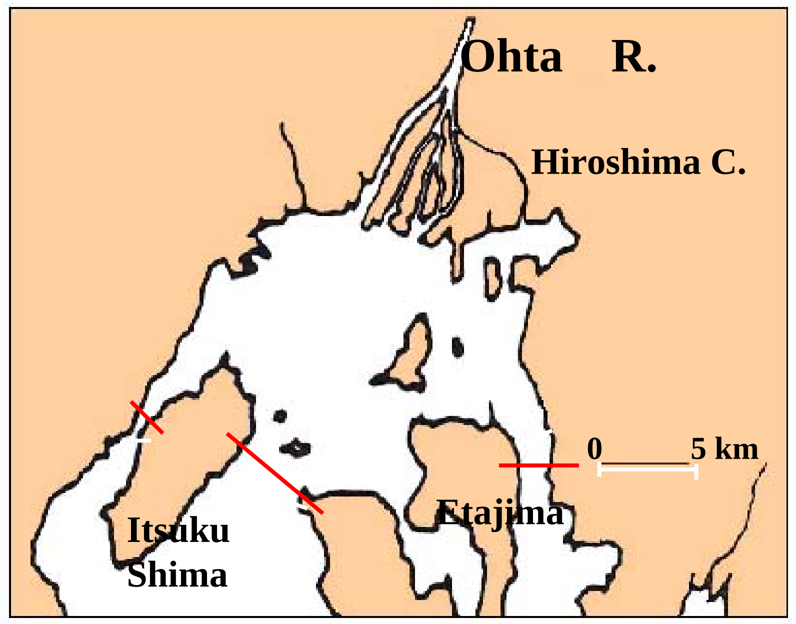


(Nukui Dam Const. Office)

An effect of dam construction
(Humborg *et al.*, 1997)



Area assumed



Ohta River estuary
(Northern Hiroshima Bay)

Area: 140 km^2
Depth: 16 m

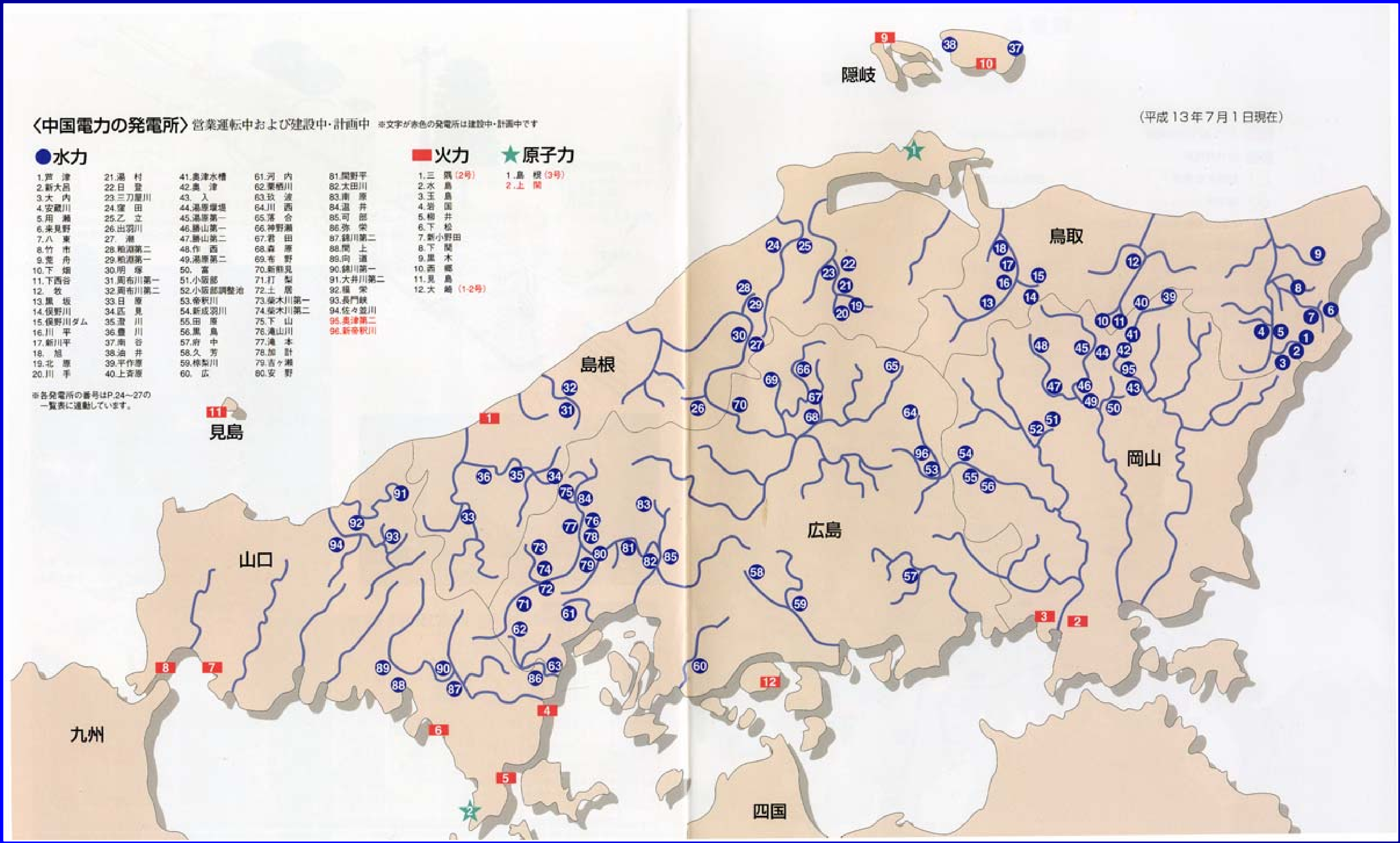
Nutrient loads

DIP ： 0.15μM day^{-1}
DIN ： 2.24μM day^{-1}
DSi ： 2.59μM day^{-1}

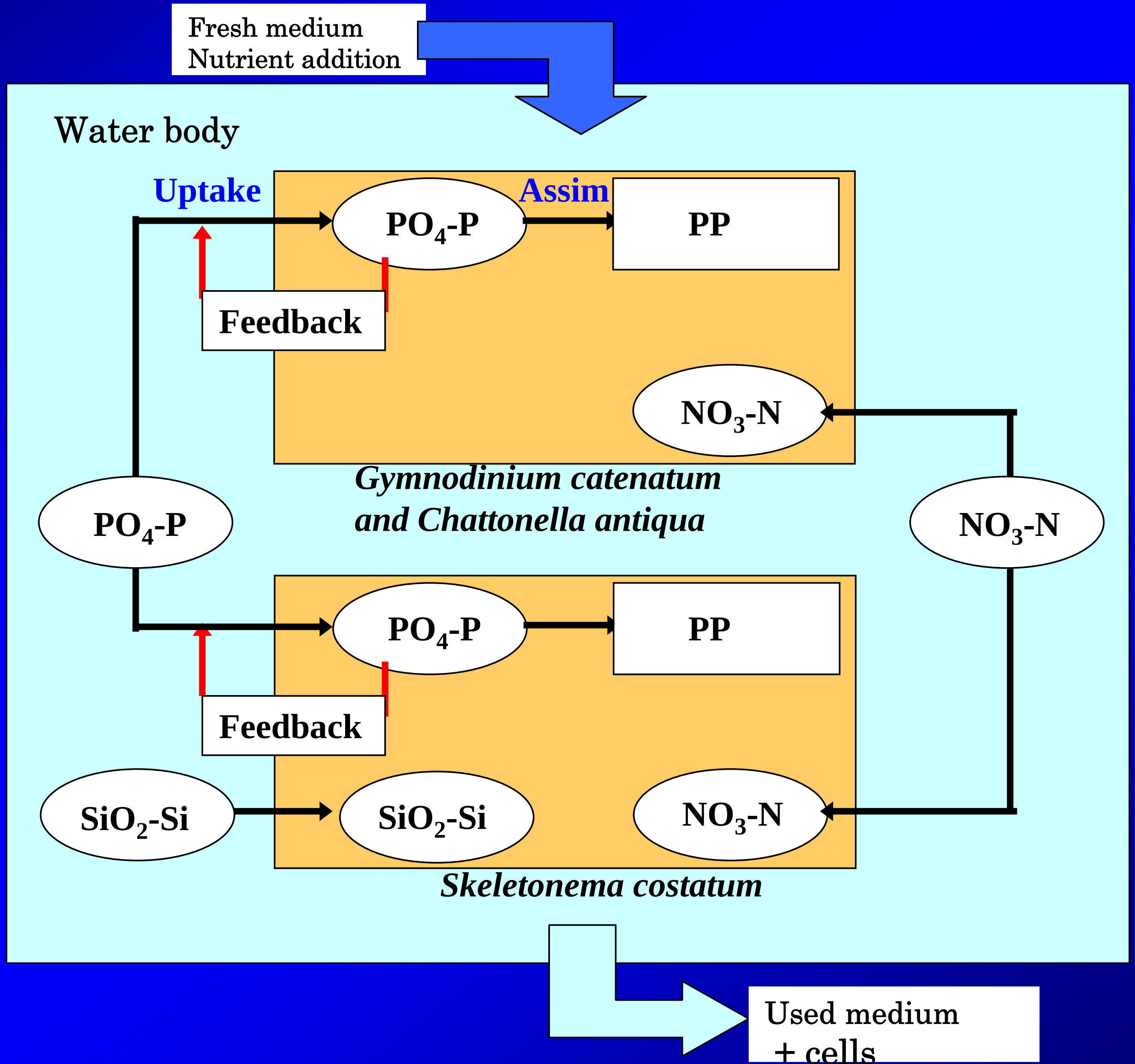
Dilution rate

0.2 day^{-1}

Dam sites in Chugoku area
(Chugoku Electric Power Co. Inc., 2001)



Model framework



Equations used

Nutrient uptake – Michaelis-Menten eq.

$\rho = \rho_{max} \cdot$ S/(Ks+S)

S : nutrient conc
ρ : uptake rate
ρ_{ma} : maximum uptake rate
Ks : half-saturation const

$\rho_{Si} = \rho_{max\ Si}(S_{Si} - S_{0Si}) / \{K_s + (S - S_{0Si})\}$

S_{0Si}: threshold DSi conc for uptake

Growth – Droop eq.

$\mu = \mu_{max}$ (1 - q_0/Q)

Q : cell quota
μ : specific growth rate
μ_{max} : max μ when Q

Time changes of variables and initial conditions

Cell density

$dN / dt = (\mu - D)N$ $\qquad N_0 = 1000$ cells l^{-1}

Nutrient concentrations

$dS / dt = load - \rho N - DS$ $\qquad$ 0.15 μg P at l^{-1}

3.0 μg N at l^{-1}

20.0 μg Si at l^{-1}

Cell quota

$dQ / dt = \rho - \mu Q$ $\qquad Q_0 = q_0$

Parameters used

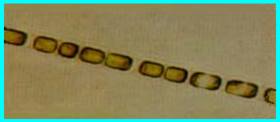
symbols		values		unit	references
	Skeletonema costatum	*Gymnodinium catenatum*	*Chattonella antiqua*		
μ_{max}	0.96	0.31	0.51	day^{-1}	Yamaguchi (1994), Yamamoto et al. (2002a), Nakamura and Watanabe (1985)
μ'_{maxP}	1.25	0.37	0.86	day^{-1}	Tarutani and Yamamoto (1994), Yamamoto (unpubl), Nakamura and Watanabe (1985)
ρ_{maxP}^{hi}	0.0384	1.42	0.14	pmol $cell^{-1}$ hr^{-1}	Tarutani and Yamamoto (1994), Yamamoto (unpubl), Nakamura and Watanabe (1985)
ρ_{maxP}^{lo}	0.000475	0.146	0.031	pmol $cell^{-1}$ hr^{-1}	calculated as $\rho_{max}^{lo}=\mu'_{max}(Q_{max}-Q_{min})$ from Morel (1987)
K_{sP}	0.68	3.4	1.9	μmol l^{-1}	Tarutani and Yamamoto (1994), Yamamoto (unpubl), Nakamura and Watanabe (1985)
Q_{minP}	0.0028	1.83	0.6	pmol $cell^{-1}$	Tarutani and Yamamoto (1994), Yamamoto (unpubl), Nakamura and Watanabe (1985)
Q_{maxP}	0.0119	11.3	1.47	pmol $cell^{-1}$	calculated as $Q_{max}=Q_{min}\cdot\mu'_{max}/(\mu'_{max}-\mu_{max})$ from Morel (1987)
μ'_{maxN}	1.25	0.36	0.74	day^{-1}	Yamamoto (unpubl), Nakamura (1985a), and for *S. costatum* , assumed to be the same as that for phosphorus
ρ_{maxN}^{hi}	0.312	6.48	0.91	pmol $cell^{-1}$ hr^{-1}	Yamamoto (unpubl), Nakamura (1985a) and see text
ρ_{maxN}^{lo}	0.00763	2.90	0.53	pmol $cell^{-1}$ hr^{-1}	calculated as $\rho_{max}^{lo}=\mu'_{max}(Q_{max}-Q_{min})$ from Morel (1987)
K_{sN}	1.0	7.59	2.81	μmol l^{-1}	Eppley *et al*. (1969), Yamamoto (unpubl), Nakamura (1985a)
Q_{minN}	0.0448	31.3	7.7	pmol $cell^{-1}$	Yamamoto (unpuble), Nakamura (1985a), and for *S. costatum* , assumed to be $Q_{minP}\times$Redfield ratio
Q_{maxN}	0.191	225	24.8	pmol $cell^{-1}$	calculated as $Q_{max}=Q_{min}\cdot\mu'_{max}/(\mu'_{max}-\mu_{max})$ from Morel (1987)
μ'_{maxSi}	1.25	-	-	day^{-1}	assumed to be the same as that for phosphorus
ρ_{maxSi}^{hi}	0.095	-	-	pmol $cell^{-1}$ hr^{-1}	Tarutani (1997)
ρ_{maxSi}^{lo}	0.00733	-	-	pmol $cell^{-1}$ hr^{-1}	calculated as $\rho_{max}^{lo}=\mu'_{max}(Q_{max}-Q_{min})$ from Morel (1987)
K_{sSi}	0.8	-	-	μmol l^{-1}	Tarutani (1997)
Q_{minSi}	0.043	-	-	pmol $cell^{-1}$	Tarutani (1997)
Q_{maxSi}	0.183	-	-	pmol $cell^{-1}$	calculated as $Q_{max}=Q_{min}\cdot\mu'_{max}/(\mu'_{max}-\mu_{max})$ from Morel (1987)
S_0Si	0.32	-	-	μmol l^{-1}	Paasche (1973)

Model runs

Fresh medium

Continuous or
Pulsed supply

Gymnodinium catenatum

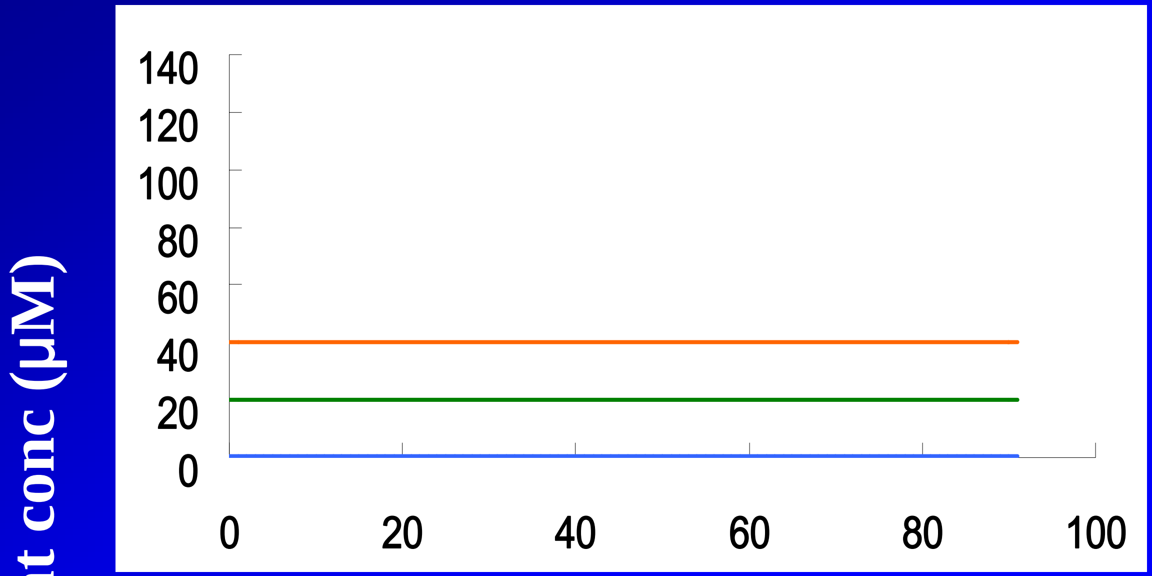


Skeletonema costatum

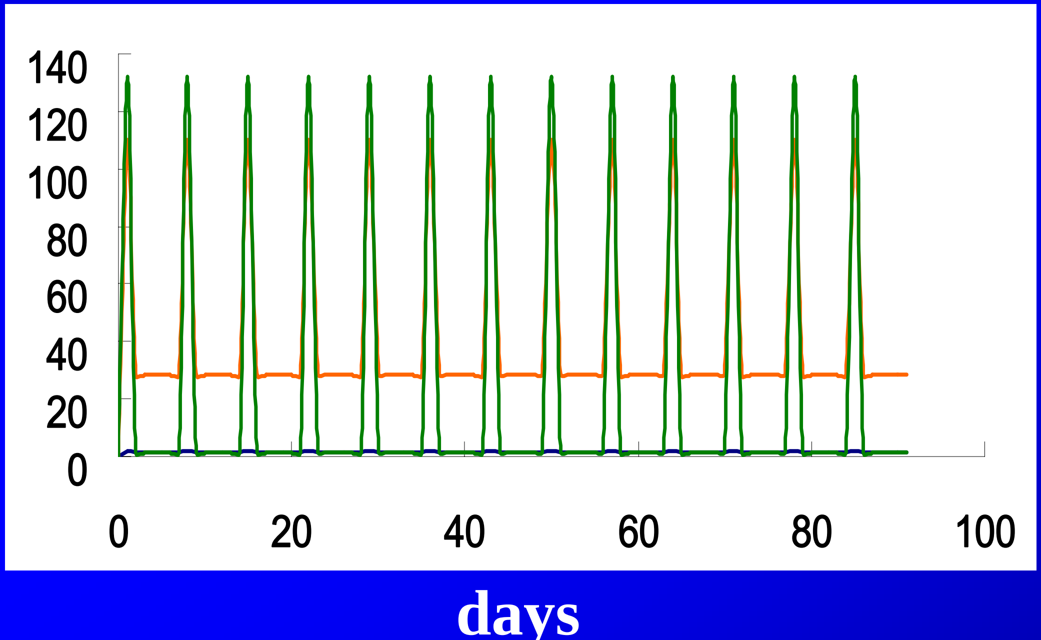
Chattonella antiqua

Unused medium
+ cells

Patterns of nutrient supply



Continuous

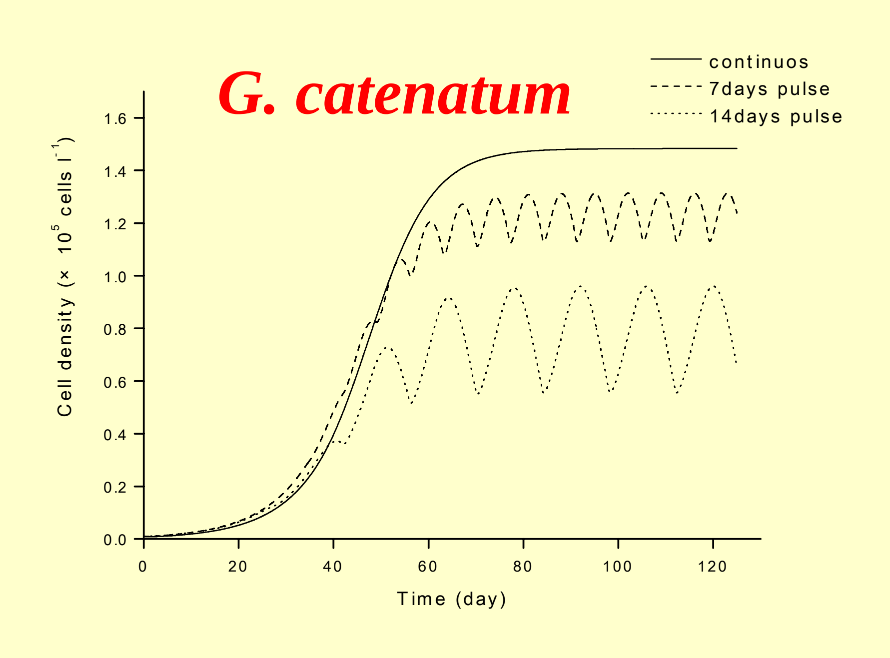


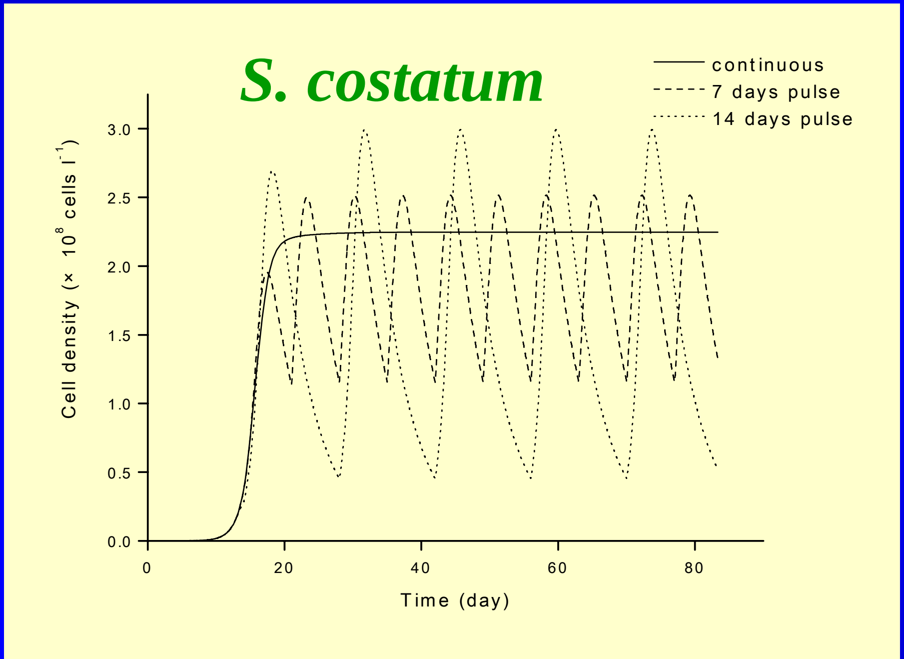
Pulsed
(7 days interval)

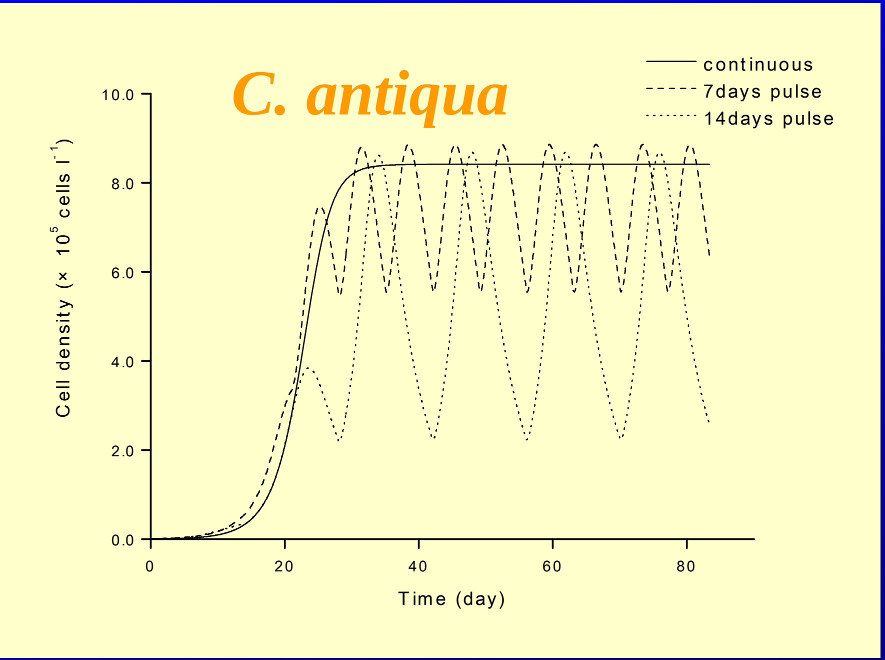
Results 1

Dynamics of a single species

Continuous nutrient supply support flagellate bloom







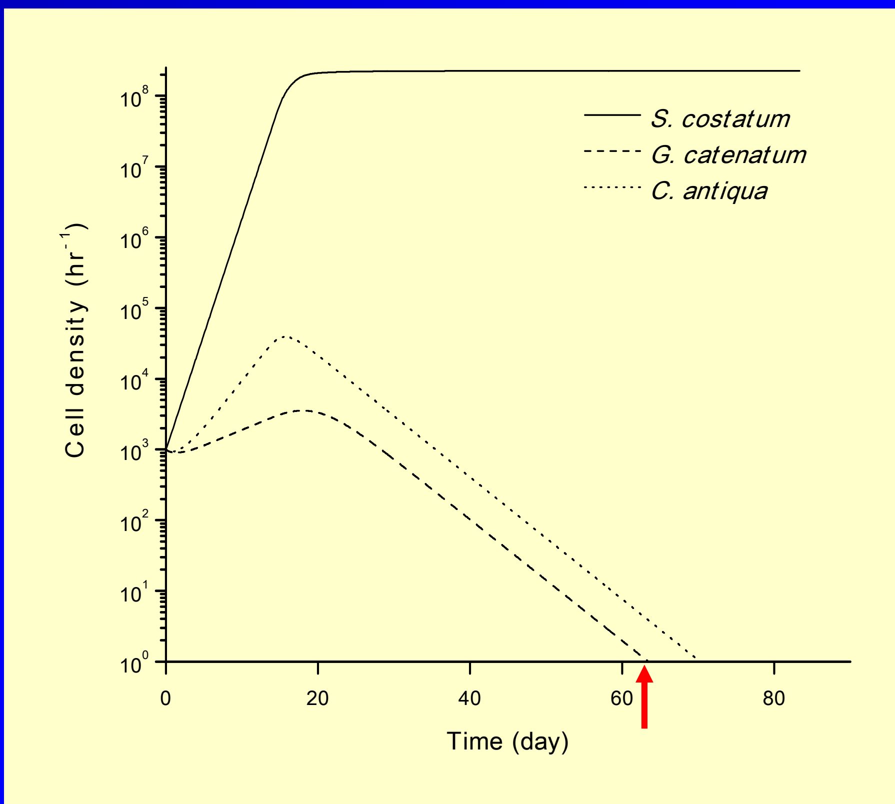
Results 2-1

Multi-species

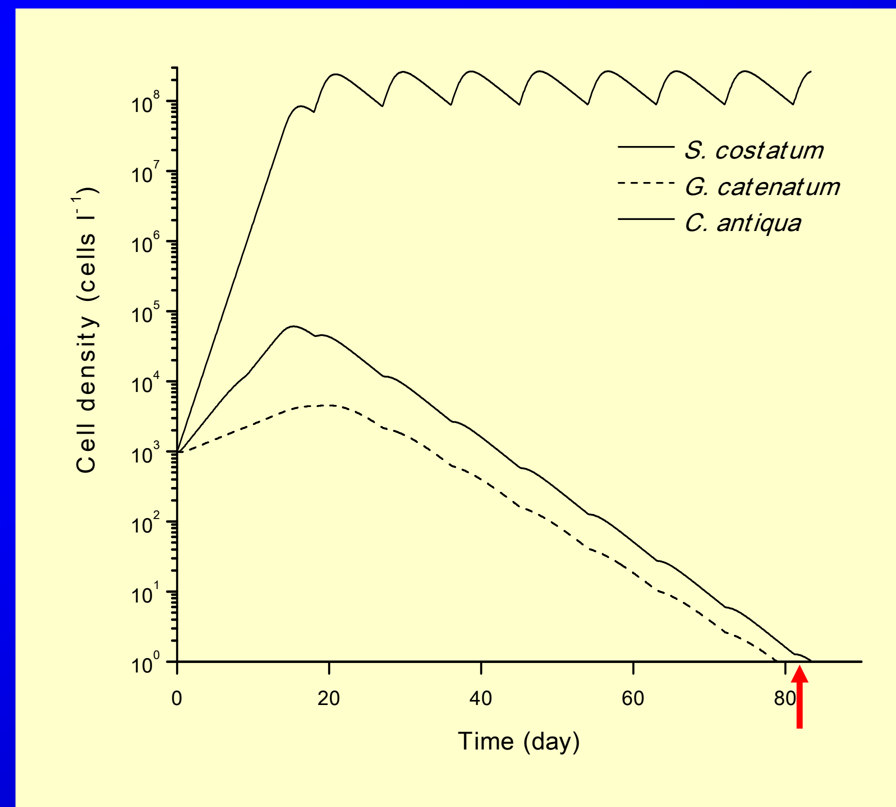
"Pulsing paradigm"

low < species diversity < high

Continuous

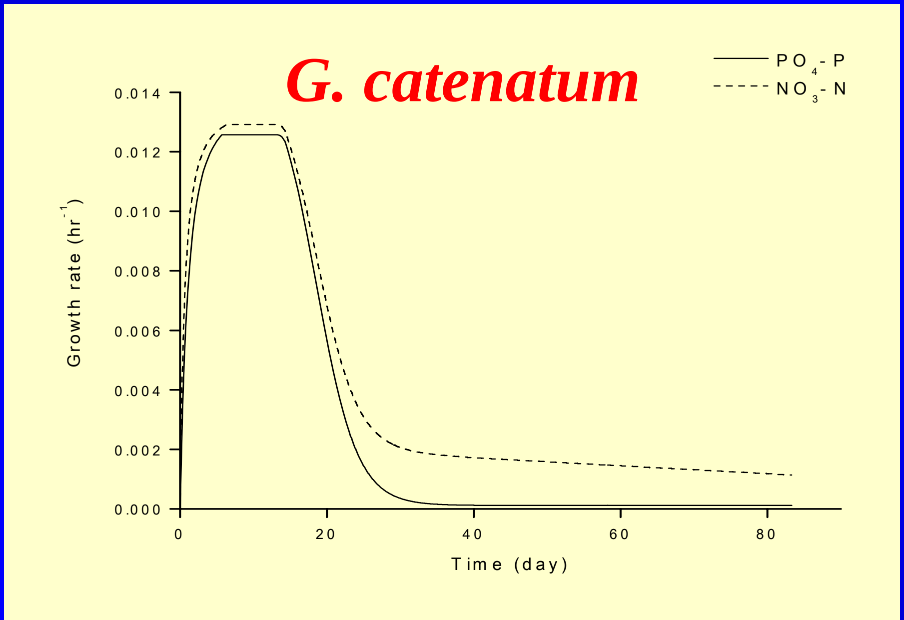


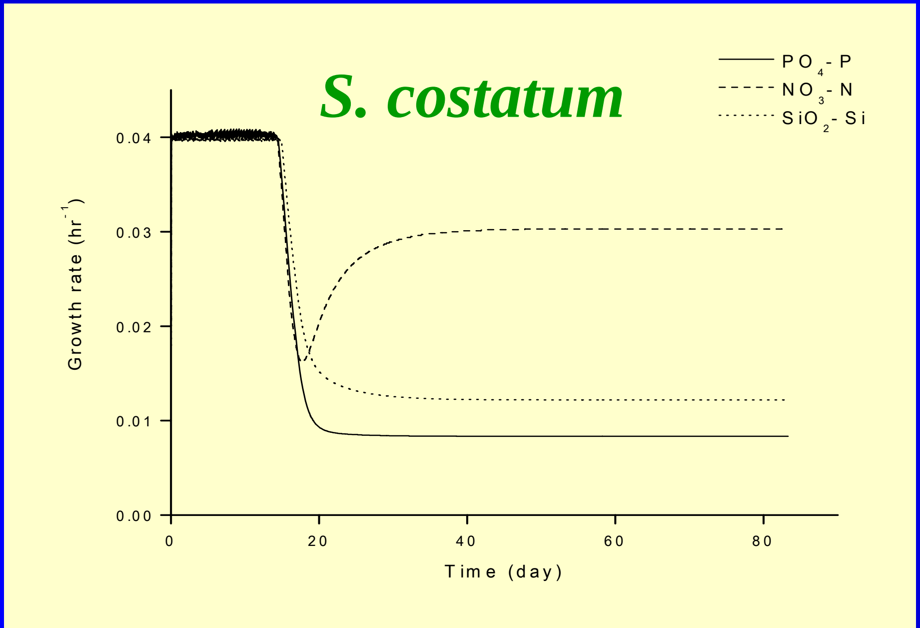
Pulsed

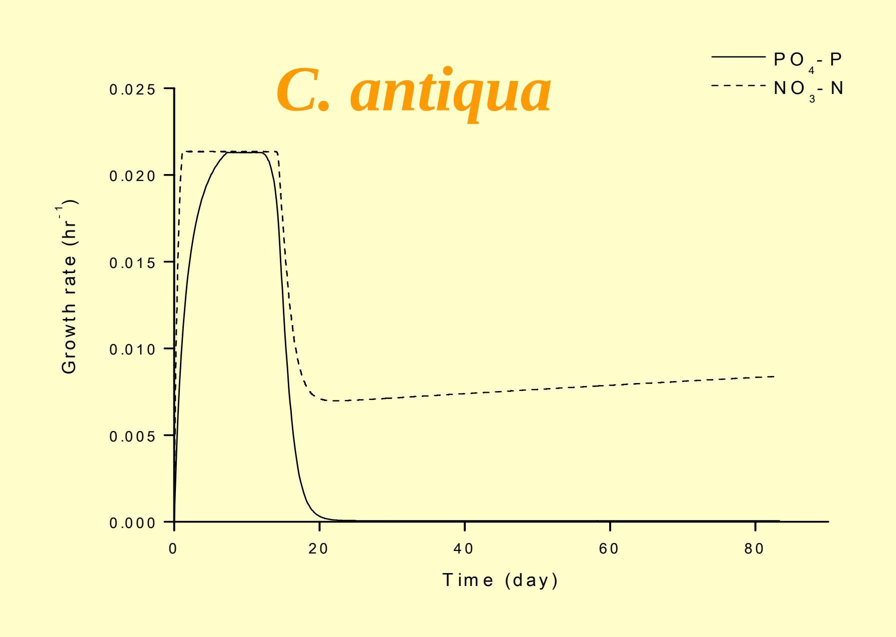


Results 2-2

Multi-species –
Limiting nutrient



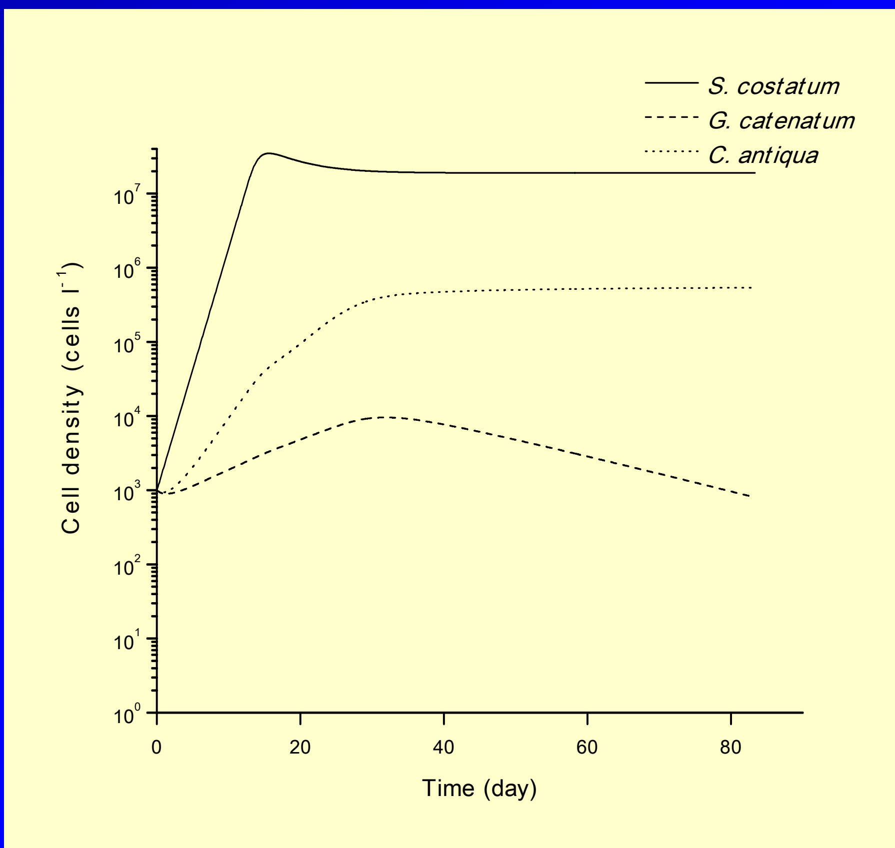




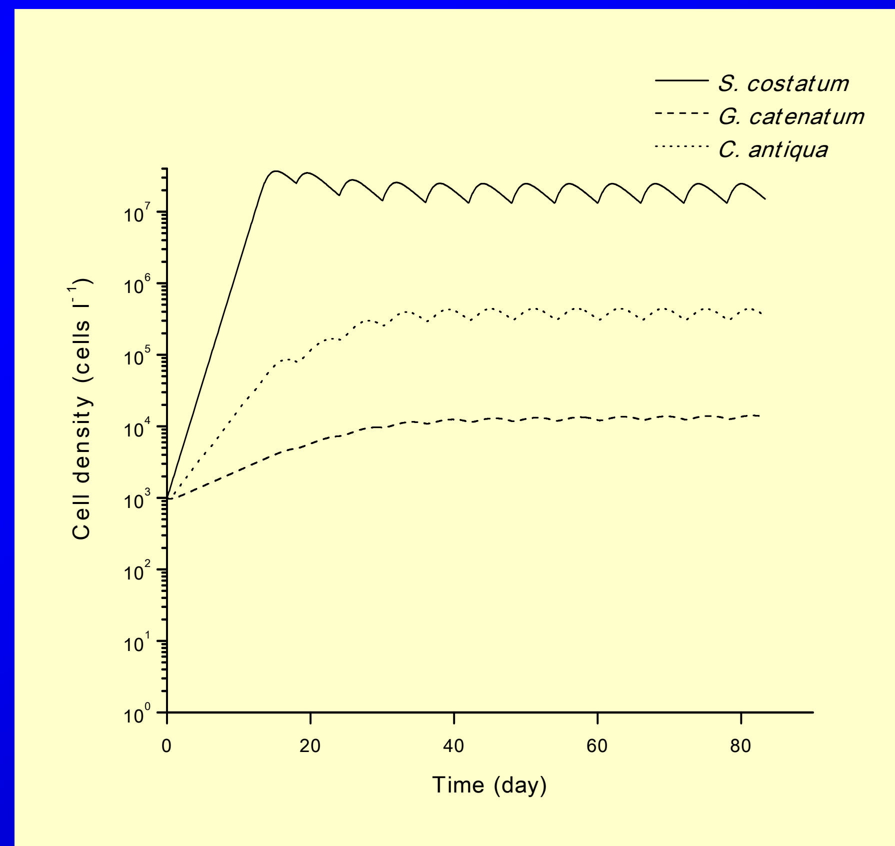
Results 3-1

Multi-species – 1/10 DSi load of the original condition

Continuous



Pulsed

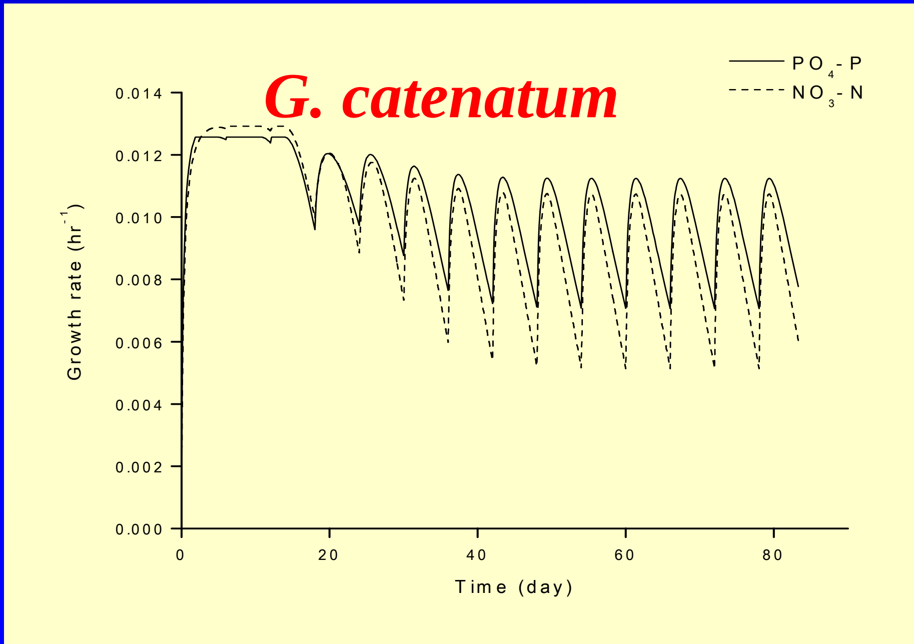


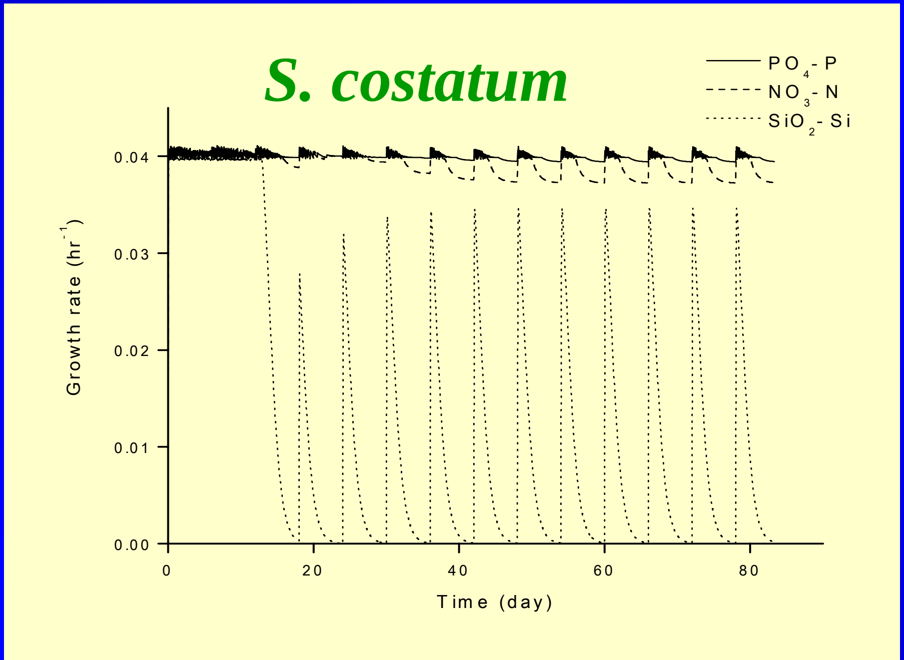
Results 3-2

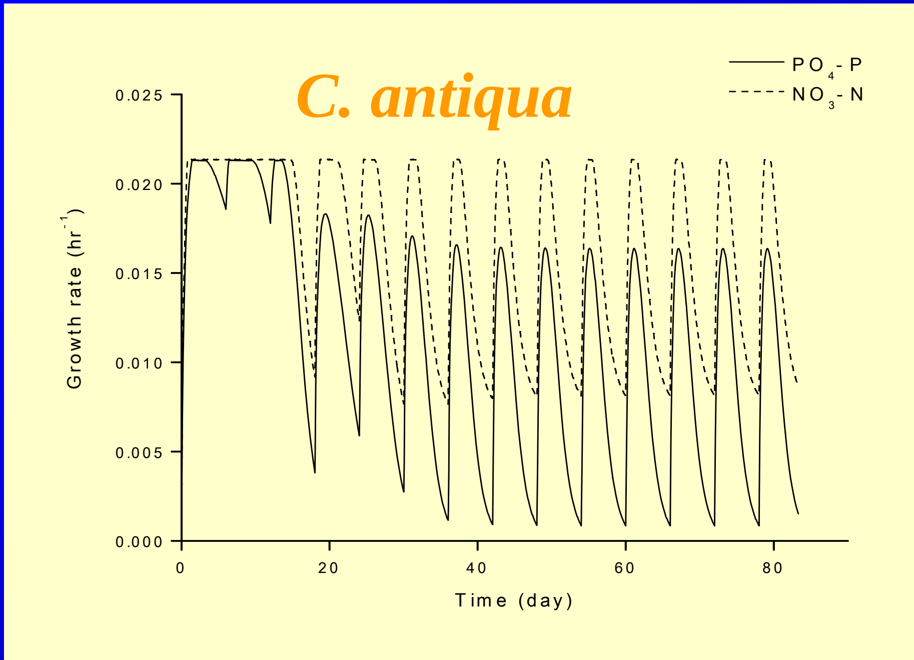
Multi-species

– Limiting nutrient

"Resource supply ratio theory"







Concluding remarks

1. Continuous nutrient supply, which may be induced by dam constructions, will work advantageously on the growth of flagellates,

2. Continuous nutrient supply will also decrease species diversity,

3. Reduction of DSi load, which may also be induced by dam constructions, will enhance the growth of harmful flagellates as a result of suppressing diatom growth.

Dam constructions could induce HAB