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Vorgeschlagene Zitierweise/Suggested citation:

Furusato, Eiichi; Hikita, Takeshi; Satou, Takayoshi; Tanaka, Shigeo; Nomura, Kazuhiro; Asaeda, Takashi (2008): Effects of the Ambient Stratification Condition in Eutrophicated Reservoirs on the Type of Antenna Pigments of Dominant Cyanobacteria. In: Wang, Sam S. Y. (Hg.): ICHE 2008. Proceedings of the 8th International Conference on Hydro-Science and Engineering, September 9-12, 2008, Nagoya, Japan. Nagoya: Nagoya Hydraulic Research Institute for River Basin Management.

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EFFECTS OF THE AMBIENT STRATIFICATION CONDITION IN EUTROPHICATED RESERVOIRS ON THE TYPE OF ANTENNA PIGMENTS OF DOMINANT CYANOBACTERIA

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ABSTRACT

We found from field observation data in two reservoirs that the hydraulic state affect the type of antenna pigments of dominant cyanobacteria. To clarify the processes of this phenomenon, we analyzed theoretically the effects of hydraulic states on phytoplankton community based on characteristics of absorption by antenna pigments and underwater light regime. By theoretical analysis we found that phycocyanin-rich cyanobacteria (PC-type) favor shallow stable stratification based on the relationship between the absorption characteristics of antenna pigment and red light penetrative optical condition. Furthermore, this hypothesis can also explain the growth condition of bloom forming cyanobacteria. This stratification condition can be estimated as the critical buoyancy frequency (N_{cr}^2). This hypothesis is verified using field data.

Keywords: antenna pigment, cyanobacteria, phytoplankton competition, stratification

1. INTRODUCTION

Algal blooms caused by harmful cyanobacteria is an important subject in water environmental management. Therefore, numerous studies have been already carried out during the past several decades. Particularly, requirement of shallow stable hydraulic states for bloom forming was pointed out by Oliver & Ganf (2000). One of the most important measures for prevention of algal bloom is the artificial circulation (Reynolds 1997), which destroy the stable hydraulic structure. From field observation data of reservoirs in which the equipment were installed, we found that hydraulic states seemed to affect the antenna pigment type of dominant cyanobacteria. Although some studies pointed out the effects of underwater light regime upon antenna pigment type of dominant phytoplankton (Glover *et al.* 1986, Callieri *et al.* 1996, Pick 1991, Vörös *et al.* 1998), the effect of hydraulic states remains unknown. We analyze theoretically the effects of hydraulic condition on phytoplankton community based on characteristics of absorption by antenna pigments and extinction of

underwater light, and attempt to explain this phenomenon using our hypothesis.

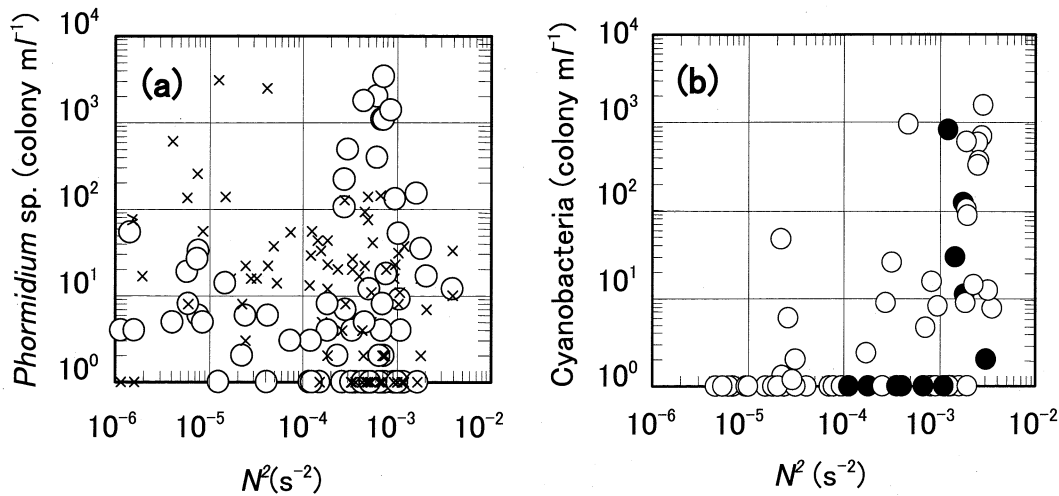


Figure 1 The relationship between N^2 and cyanobacteria abundance. (a) *Phormidium* sp in the K dam reservoir. ○, PC type; ×, PE type. N^2 was calculated at total (15~20m) depth. (b) large colony cyanobacteria (mainly *Microcystis*) in the H dam reservoir. ○, before artificial circulation; ●, after artificial circulation. N^2 was calculated at 5m.

2. FIELD OBSERVATION DATA

In order to optimize planning and managing artificial destratification, useful, simple, and a reasonable index is necessary. We investigated the relationship between the abundance of cyanobacteria and buoyancy frequency (N^2) in two eutrophic reservoirs in Japan (Figure 1). Different type of artificial destratification equipments were installed in each reservoir for the prevention of water bloom. The dominant cyanobacteria was *Phormidium tennue* in the K dam reservoir and was mainly *Microcystis aeruginosa* in the H dam reservoir

3. THEORY – ANTENNA PIGMENTS AND BUOYANCY FREQUENCY HYPOTHESIS –

We propose a hypothesis of antenna pigments-buoyancy frequency. This theory explains how optical and hydraulic characteristics of water bodies affect *in situ* phytoplankton population competition.

As described above, there have been already some studies, which focused on the relationship between antenna pigment and underwater light spectrum. For example in cyanobacteria, roughly, there are two types of antenna pigment; PC-type, which mainly absorb red color long-wave light; PE-type, which mainly absorb green color shorter-wave length than red (Vörös *et al* 1998). Which type becomes dominant depend on most penetrative wave length underwater light in many lakes and reservoirs. However, based on that photosynthetic ability of phytoplankton subject to depend on hydraulic states, such as mixed depth (Reynolds 1997) or critical depth (Sverdrup 1953) and critical turbulence (Huisman *et al.* 1999), we tried to propose a new theory. That is, phytoplankton population competition can be affected by not only underwater light regime but also hydraulic state through the absorption characteristics of antenna pigments.

For example, if we assume competition between two types of antenna pigment cyanobacteria, that is PC-type and PE-type, the explanation given below seems possible. Shallow mixed depth would make the conditions favorable for the PC-type because red light exists only in the shallow layer. Converse condition favor the PE-type. Under some assumptions, this competition state can be estimated by whether mixed depth reaches the equilibrium depth (z_{eq}) (Figure 1). N^2 is a useful index of hydraulic stability (Imberger & Patterson 1990) and based on this, we propose that N^2 between surface and arbitrary depth would be useful index for the estimation of phytoplankton population competition.

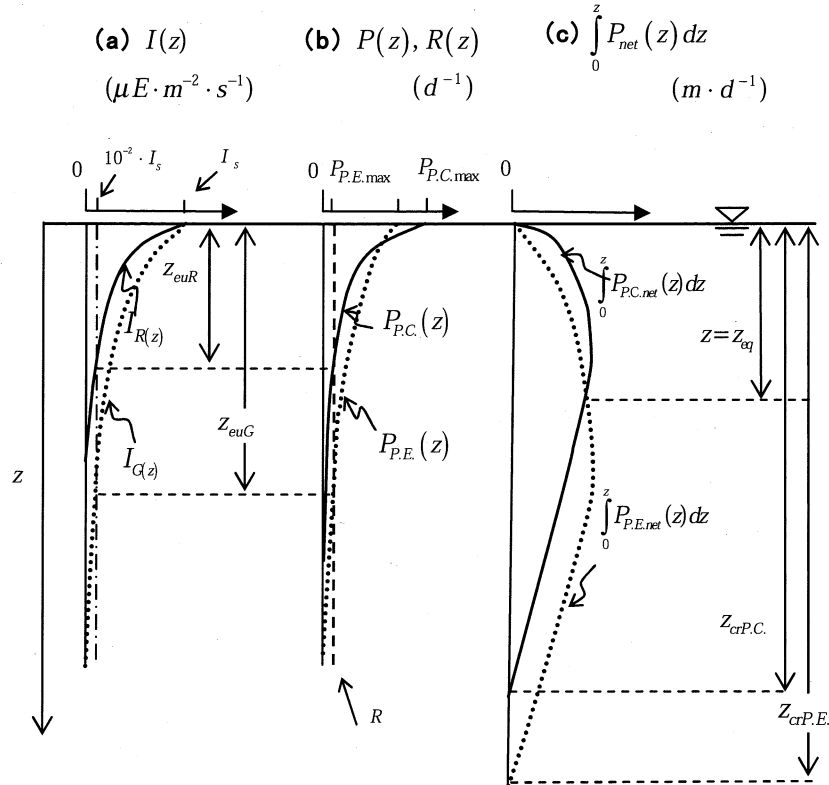


Figure 2 Diagrammatic representations of vertical profiles of optical and photosynthetic factors. (a) photon flux of red and green light (b) photosynthesis and respiration at depth z of PC type and PE type (c) depth integral net photosynthesis ($DINP$) of each antenna pigments type. (z_{eu} is euphotic depth for each type, z_{eq} is equilibrium depth for each types competition, z_{cr} is critical depth (Sverdrup 1953))

$$\int_0^{zm} P_{P.C.net} = \frac{P_{P.C.max}}{\epsilon R} \cdot \log \left(\frac{I_{kP.C.} + I_{R_s}}{I_{kP.C.} + I_{R_s} \exp^{-\epsilon R \cdot zm}} \right) - R_{P.C.} \cdot zm \quad (1)$$

Where, $P_{P.C.}$ is the gross photosynthetic rate (d^{-1}), $P_{P.C.max}$ is the light saturated gross photosynthetic rate (d^{-1}), I_{R_s} is the underwater photon flux density of red light at surface ($\mu E \cdot m^{-2} \cdot s^{-1}$), ϵR is the extinction coefficient of red light (m^{-1}), $I_{kP.C.}$ is the half saturation photon flux density corresponding to red light of PC-type ($\mu E \cdot m^{-2} \cdot s^{-1}$). The equations for PE-type can be expressed by converting PC given in the subscript into PE and R into G. Following assumptions are used: First, PC-type depends on only red light and PE-type depends on only green light in their photosynthesis (Callieri et al. 1996). Second, each wave length of light attenuated has an inherent extinction coefficient. Third, each type of phytoplankton is distributed uniformly in the mixed layer.

4. THEORETICAL ANALYSIS

The effect of mixed depth on competition between PC-type and PE-type

In order to analyze our hypothesis, we used some assumptions (See Figure 2 caption). Following these assumptions, depth integrated net photosynthesis ($DINP$) of each type can be estimated by the following equation (also see Figure 2). Figure 2 shows these vertical profiles with a comparison of PC-type and PE-type. This competitive relation can be estimated as the ratio of $DINP$ of each pigments types ($rPCPE$).

$$rPCPE = \int_0^{z_m} P_{P.C.net} / \int_0^{z_m} P_{P.E.net} \quad (2)$$

We analyzed the behavior of $rPCPE$ as a relationship between the ratio of eG and eR (re) and mixed depth. Figure 3 shows the analytical results based on biological parameters of picocyanobacteria (*Synecoccus* sp.) (Callieri *et al.* 1996). There are five areas of $rPCPE$ according to z_m/z_{eu} and re . Except for area V, it is possible in four areas that $DINP$ of both or each type is positive. Only in area V, mixed depth is too deep for positive $DINP$ of both types. It gives rise to these five areas that smaller re and smaller z_m/z_{eu} make PC-type efficient than PE-type as well as that different critical depths for each pigment type. The dependence characteristics of $rPCPE$ on re agrees with previous studies (Glover *et al.* 1986, Callieri *et al.* 1996, Pick 1991, Vörös *et al.* 1998). Particularly, in moderate re , mixed depth can determine dominant antenna pigment type.

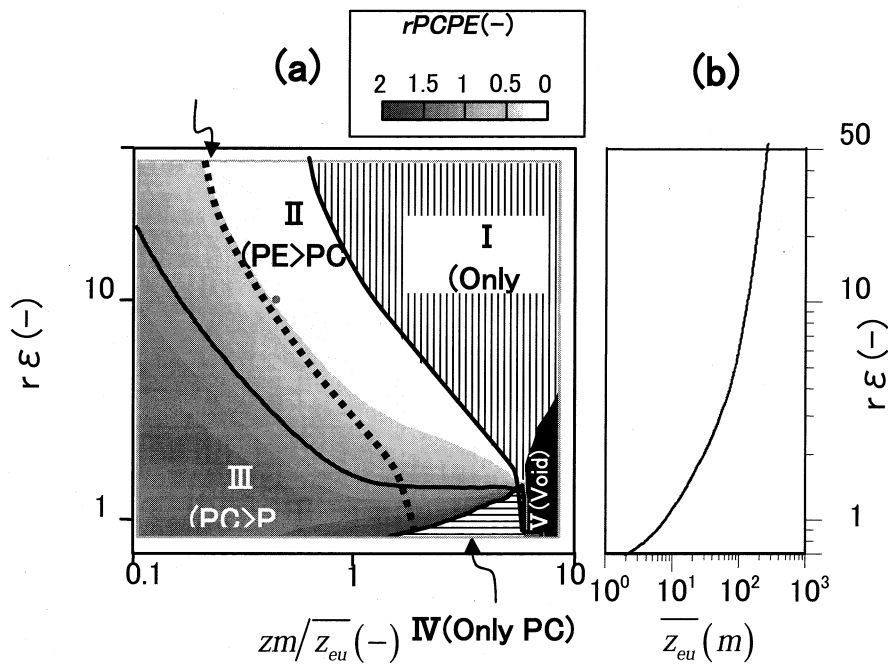


Figure 3 $rPCPE$ as a function of z_m/z_{eu} and re , and euphotic depth. (a) Solid thick lines indicate boundary of each area and dashed thick line indicates critical depth of LCPC (ex. *Microcystis aeruginosa*). Particularly, the solid thick line bounded between area II and III is z_{eq} as shown in Figure 1(c).; (b) wave length-smoothed euphotic depth in accordance with re based on Jerlov's water types (Jerlov 1976). Since euphotic depth is strictly defined as the depth in which gross photosynthesis is equal to respiration rate, even in same water body it depends on phytoplankton species. Considering conventional water quality index, however, we calculated the euphotic depth using transparency. Thus, this euphotic depth does not consider any specific phytoplankton species.

Addition to this analytical result, we try to analyze large colony PC-type cyanobacteria (LCPC) based on the parameters of *Microcystis aeruginosa* (colony form) (Reynolds *et al.* 1981, Reynolds 1989). Although it is similar to the PC-type picocyanobacteria that the critical depth is greater in low re , critical depth of LCPC is shallower than picocyanobacteria and deepest critical depth is only three times as that of euphotic depth. The reason for this is lower maximum photosynthetic rate of LCPC (Reynolds 1997). Particularly, in the higher re area, which correspond to a high transparency water body, extremely small zm/zeu allows net photosynthesis to become positive. Therefore this is one of the reasons why the growth of LCPC is restricted to eutrophic lakes and reservoirs (Reynolds 1997) that tend to be lower in transparency and has a lower re . However, even in these eutrophic lakes and reservoirs, the condition that mixed depth exceeds the depth as much as several times of euphotic depth is considered not to be suitable for LCPC.

Critical stability and wind speed

As described below, we analyzed the index of estimation for *in situ* mixing condition for phytoplankton population competition. Generally, the stability of stratification can be estimated by N^2 (Imberger & Patterson 1990). However, this can only represent stability, but not actual mixing states. Considering the time scale of phytoplankton dynamics, the major external forcing factor can be assumed to be the wind. Mixing condition based on wind stirring and stratification can be estimated from Wedderburn number (Imberger & Patterson 1990). Therefore, we combined simply these two parameters and obtained the following equation for critical N^2 (N_{cr}^2).

$$N_{cr}^2 = \rho_a / \rho \cdot C_D \cdot L \cdot U_{10}^2 \cdot H^{-3} \quad (3)$$

Where ρ_a is the density of air, H is the depth, C_D is the drag coefficient, U_{10} is the wind speed at height 10 m above water surface, L is the basin scale. As shown in the Figure 4, if we assume ordinary wind velocity at U_{10} as several m/s and depth at $zm=10m$, N^2 under $O(10^4)$, which corresponding to N_{cr}^2 to represent mixing condition.

Figure 4 The relationship between stability (Buoyancy frequency N^2) and wind velocity corresponding to $W=1$ solid thin line, $zm=5m$; dashed thick line, $zm=10m$; solid thick line, $zm=20m$. Each line represents critical values of mixing or sustaining stratification corresponding to each different mixed depth. In this figure, the range of N_{cr}^2 at $z=10m$ in accordance with ordinary wind speed is indicated

5. DISCUSSION

As shown in Figure 2, in the range of medium to low re condition corresponding to many inland water bodies (Kirk, 1983), stratification condition can affect the competition dynamics of different antenna pigment type. Because maximum photosynthetic rate of large colony algae tends to be smaller (Reynolds 1997), critical depth of LCPC tends to be shallower. Furthermore, from theoretical analysis, actual mixing state can be estimated by N^2 . In both reservoirs shown in Figure 1, N^2 and the corresponding calculated depth exceeds N_{cr}^2 and zeq , respectively seems suitable for PE-type dominance. Furthermore, N_{cr}^2 of both reservoirs agree with Reynolds's empirical critical value of S-strategy type phytoplankton (Reynolds 1993) (such as *M.aeruginosa*, *Volvox*, *Peridinium*, characterized by bigger size, and slower growth rate).

However, in this research, there are several limitations such as the effect of other

populations, the assumption of steady state, and the generality of *re* (Prieur & Sathyendranath 1981). Furthermore, for investigation in relation to pigments of cyanobacteria, consideration about chromatic adaptation (Tandeau 1977) is necessary. However, in addition to the agreement with some of previous studies about optical viewpoints (Pick 1991, Vörös *et al.* 1998), and requirement of shallow stable stratification for cyanobacterial bloom (Huisman 1999, Wallane & Hamilton 2000), N_{cr}^2 which we proposed is practical and useful for planning and management of artificial destratification.

In the future, it is necessary to verify this hypothesis using more field data, and also to investigate the relation to other factors such as buoyancy regulation of cyanobacteria (Oliver & Ganf 2000). Moreover, for optimization of artificial destratification, it is necessary to clarify arbitrary equipment specification based on previous hydraulic studies (Asaeda & Imberger 1993).

REFERENCES

- Asaeda, T & Imberger, J. (1993) Structure of bubble plumes in linearly stratified environments, *J. Fluid Mech.* 249: 35-57.
- Callieri, C., E. Amicucci, R. Bertoni & L. Vörös (1996) Fluorimetric characterization of two picocyanobacteria strains from different underwater light quality. *Int. Rev. ges. Hydrobiol.* 81:13-23
- Glover HE., Keller MD & Guillard RRL (1986) Light quality and oceanic ultraphytoplankton. *Nature* 319: 142-143
- Huisman, J., P. van Oostveen & F.J. Weissing (1999) Critical depth and critical turbulence: two different mechanisms for the development of phytoplankton blooms, *Limnol. Oceanogr.* 44: 1781-1787
- Imberger, J. and Patterson, J.C. (1990) Physical limnology, *Advances in applied mechanics*, 27: 303-475
- Jerlov, N.G. (1976) *Marine Optics*. Amsterdam: Elsevier, 231pp
- Kirk, J.T.O. 1983. *Light and photosynthesis in aquatic ecosystems*. Cambridge University Press. London, 401 pp.
- Oliver, R.L. and Ganf, G.G. (2000) Freshwater Blooms. In: Whitton, B.A. and Potts, M. (eds) *The Ecology of Cyanobacteria*, pp 149–194. Kluwer Academic Publishers
- Pick, F.R. (1991) The abundance and composition of freshwater cyanobacteria in relation to light penetration. *Limnol. Oceanogr.* 36: 1457-1462
- Prieur, L. & S. Sathyendranath (1981) An optical classification of coastal and oceanic water based on the specific spectral absorption curves of phytoplankton pigments, dissolved organic matter, and other particulate materials. *Limnol. Oceanogr.* 26: 671-689
- Reynolds, C. S. (1989) Physical determinants of phytoplankton succession. In: U. Sommer (ed.), *Plankton ecology* pp. 9-56. Brock-Springer, Madison
- Reynolds, C.S. (1993) Swings and roundabouts: engineering the environment of algal growth. In: K.H. White, E. G. Bellinger, A.J. Saul, M. Symes and K. Hengry (eds.), *Urban waterside regeneration, problems and prospects*, pp. 330-349. Ellis Horwood, Chichester
- Reynolds, C.S. (1997) *Vegetation processes in the pelagic: A model for ecosystem theory*, Ecology Institute, Oldendorf/Luhe, Germany. 329pp
- Reynolds, C.S. Jaworski, G.H.M. Cmiech, H.A. & Leedale, G.H. (1981) On the annual cycles of the blue-green algae *Microcystis aeruginosa* Kütz. Emend. Elenkin. *Philosophical Transactions of the Royal Society of London*, B 293, 419-477
- Sverdrup, H.U. (1953) On conditions for the vernal blooming of phytoplankton. *J. Cons. Explor. Er.*, 18, 287-295

- Tandeau de Marsac, N. (1977) Occurrence and nature of chromatic adaptation in cyanobacteria. *J. Bacteriol.*, 130, 82-91
- Vörös, L., Callieri, C., Bertoni KV & Bertoni, R. (1998) Freshwater picocyanobacteria along trophic gradient and light quality range. *Hydrobiologia* 369/370: 117-125
- Wallece, B.B. & Hamilton, D.P. (2000) Simulation of water-bloom formation in the cyanobacteria *Microcystis aeruginosa*. *J. Plankton Res.* 22: 1127-1138