# EFFECTS OF RIVER DISCHARGE ON GROWTH OF PERIPHYTON IN SAND RIVER

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**Abstract:** Periphyton is known to be one of major primary producers for river ecosystem. While the growth of periphyton usually observed on the stone surface in gravel river, the large growth of periphyton is sometimes seen even in sand river with relatively small river discharge. In the present study, field observations and numerical simulations were performed to investigate the growth of periphyton in sand river. In the field observation, the growth of periphyton on fixed sand bed was measured weekly. The results of the field observations show that the large growth of periphyton occurs in sand river until the bed material sands have not moved. An integrated numerical simulation model is presented to describe the growth of periphyton at observed river reach, and a series of numerical simulations were performed to study the effect of river discharge on growth of periphyton in the sand river. The results of the numerical simulations show that the net primary production of periphyton decreases with the river discharge. These results suggest that the reduction of river discharge at ordinary water stage strongly affects the primary productivity of periphyton even in sand river.

**Keywords**: Periphyton, sand river, primary production, river discharge

## 1. INTRODUCTION

Periphyton is known to be one of major primary producers for river ecosystem, and it develops bio-film type communities on solid surface submerged in water (MacIntire (1973), Minshall (1978), Saravia et al. (1998)). In natural streams, the periphyton communities are usually seen on the surface of gravel stone of shallow river bed and/or on the surface of submerged structures. The growth of periphtyon is expected to be rarely observed in sand river reach because of high mobility of bed materials and shortage of solar illumination due to relatively large water depth compared with gravel reach. Nevertheless the large growth of periphyton is sometimes seen even in sand river where river discharge and water depth are small enough to provide the stable habitat for periphyton.

For rivers running through agricultural area, river water is often diverted to the agricultural fields for irrigation use, which decreases river discharge during ordinary water stage. This decrease of river discharge may induce the stabilization of bed materials and the resulting large growth of periphyton even in sand river. In order to understand the base of river ecosystems in sand river, it is important to know the relation between river discharge and growth of periphyton on sand bed.

In the present study, the field measurement was performed in a sand river to understand the characteristics of growth of periphyton on sand bed. A series of numerical simulations were conducted to know the effect of river discharge on the primary production of periphyton in sand river.

## 2. FIELD OBSERVATION

### 2.1 Method og the Field Observation

### 2.1.1 Observation Site

The field observation was performed at Yahagi River in Japan. The length of the river is 117 km, and the area of the river basin is about 1,830 km$^2$. The large part of the middle and lower basin of the river are used for agriculture field, and about 30 m$^3$/s of the river discharge is continuously distributed to the agricultural field during irrigation season at a diversion weir locating at 34.6 km upstream from the river mouth. This water intake decreases the river discharge at the lower reach of the river from 50 ~ 60 m$^3$/s down to about 20 ~ 30 m$^3$/s, decreasing the mobility of river bed materials. Consequently, the river bed at the lower reach of Yahagi River has been strongly stabilized during ordinary water stage, and the growth of periphyton is sometimes seen on the sand bed surface.

The observation area locates at 17 km upstream from the river mouth. The cross-sectional bed elevation of the observation site is depicted in Fig. 1. The cross-sectional averaged water depth of the observation site is less than 1 m during ordinary water stage, indicating that the large part of solar illumination can reach to the bed surface. Fig. 2 depicts the grain size distribution of bed materials, which shows that the median diameter of the bed materials is about 1.5 mm, and the observed area is classified into a typical sand river reach.

### 2.2.2 Observation Methods

The field observation was conducted to know the growth of periphyton on the surface of sand river bed during summer in 2004 and winter in 2004 and 2005. The sand sampled at the observed area was classified into following 4 different size groups by using sieves; D1 group: diameter less than 0.085 mm, D2 group: diameter

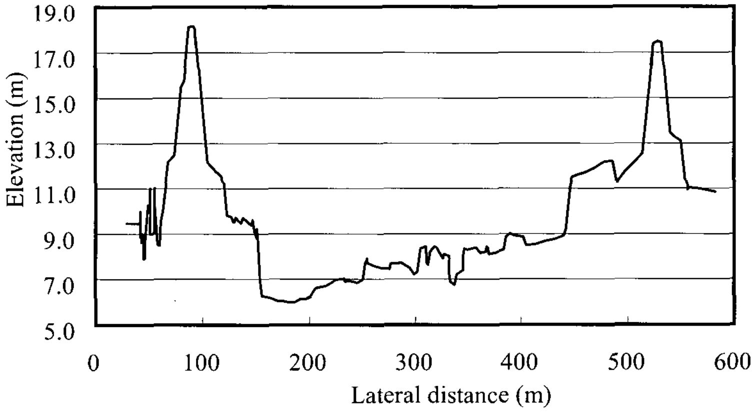


**Fig. 1. Cross sectional elevation of the observed area**

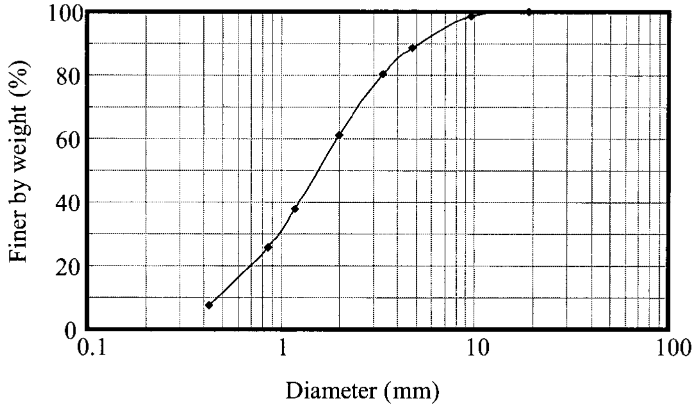


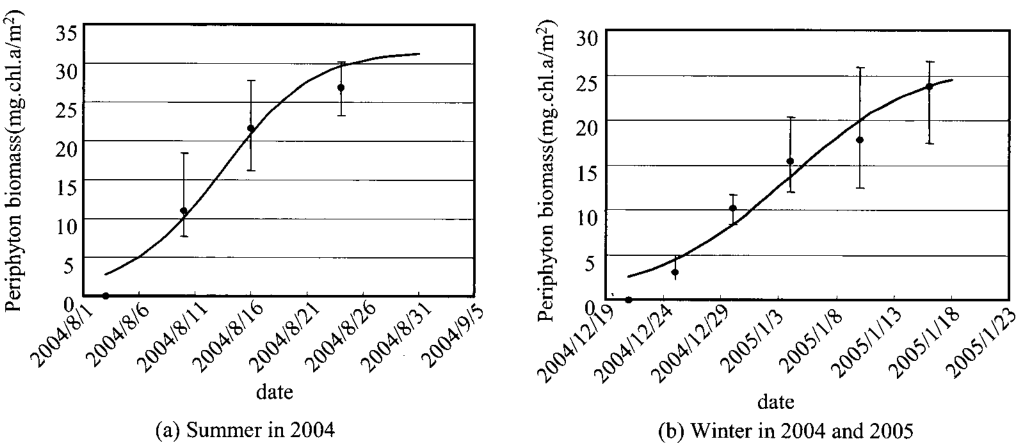
**Fig. 2. Grain size distribution of the bed material sands**

ranging 0.085 mm to 1.18 mm, D3 group: diameter ranging 1.18 mm to 2.00 mm, and D4 group: diameter larger than 2.00mm. Sand of the each size group was pasted on the square-shaped acrylic plates whose size is 8 cm x 8cm. The acrylic plates were settled on the frame, and the frame was installed onto the river bed. Three acrylic plates of each sand size group were picked up weekly, and the periphyton growing on them was removed by tooth brush. The amount of periphyton was quantified in terms of the amount of chlorophyll a which is known to be a major photosynthetic pigment of plant. The amount of chlorophyll a was measured by using a spectrophotometer in accordance with the method proposed by SCOR/UNESCO (1975).

## 3. RESULTS OF THE FIELD OBSERVATION

### 3.1 Growth of Periphyton

Figs. 3 (a) and (b) depict the temporal variation of the chlorophyll a in summer of 2004 and in winter of 2004 and 2005, respectively, in which the black circles indicate the average value of the amount of chlorophyll a for all periphyton samples, and the vertical bars mean the range of scatters of the data. While the scatter of the data



(a) Summer in 2004

(b) Winter in 2004 and 2005

**Fig. 3. Growth of periphyton on the fixed sand surface**

the data is considerably large, the average value of the chlorophyll a is found to increase with time. Comparing the growth of periphyton between summer and winter, the relatively large growth is observed in summer season.

It has been known that the temporal variation of biomass can be often approximated by the following logistic equation :

$$\frac{dM}{dt} = \mu M\left(1 - \frac{M}{K}\right) \quad (1)$$

in which $M$ is the amount of biomass, $\mu$ is specific growth rate, and $K$ is environmental capacity of biomass. The specific growth rate $\mu$ represents the net growth speed of biomass at relatively early growth stage which can be estimated from the balance of photosynthesis, respiration and immigration. In general, the rate of photosynthesis takes larger value than the rates of respiration and immigration at the early growth stage, and, therefore, the value of the specific growth rate can be approximately evaluated by the rate of photosynthesis. The environmental capacity $K$ is the maximum value of biomass at equilibrium growth stage. The values of $\mu$ and $K$ were estimated by fitting the Eq. (1) to the observed periphyton biomass by using least mean square approximation, and the results are summarized in Table 1. It was found that the specific growth rate and the environmental capacity of periphyton take larger values in summer than those in winter, suggesting photosynthetic activity in summer is larger than that in winter.

**Table 1. Growth parameters of the periphyton**

| | summer | winter |
|---|---|---|
| Specific growth rate $\mu$ (day$^{-1}$) | 0.24 | 0.17 |
| Environmental capacity $K$ (mg.chl.a/m$^2$) | 31.5 | 26.3 |

### 3.2 Effects of Grain Size of Bed Materials

Fig. 4 shows the growth of periphyton on the different grain size groups. It was found that the growth of the periphyton does not vary with the grain size of the sands, indicating that the growth of periphyton is not affected by the grain size of substrata as long as the bed material sands have not moved.

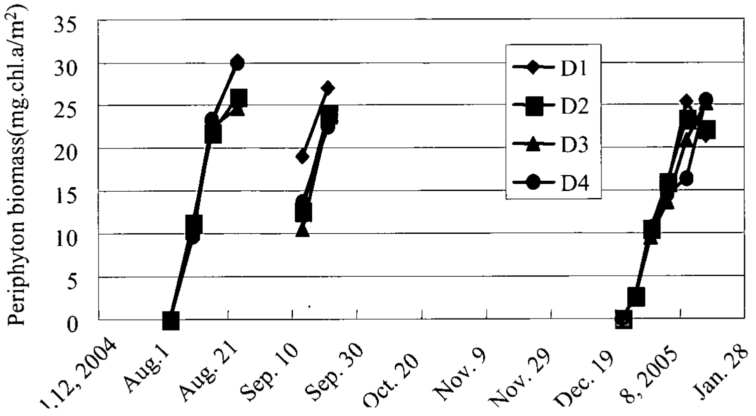


**Fig. 4. Growth of periphyton on the different grain size sands**

# 4. NUMRICAL SIMULATION

## 4.1 Numerical Simulation Model

### 4.1.1 Outline of the numerical simulation

Fig. 5 shows the flow chart of the present numerical simulation, which consists of the analysis of frequency of bed material movements and the simulation of growth of periphyton during the period that the bed material sands have not moved. In the computation of frequency of bed material movements, the tractive force on river bed $\tau_*$ is estimated under the uniform flow assumption by using the observed data of river discharge and cross-sectional geometry, and the critical tractive force $\tau_{*c}$ is calculated by using Iwagaki formula (Iwagaki (1956)). Comparing between $\tau_*$ and $\tau_{*c}$, the amount of periphyton $M$ is estimated to 0 during the period of $\tau_*>\tau_{*c}$, and it is calculated by the numerical integration of the logistic equation, Eq. (1), during the period of $\tau_*<\tau_{*c}$.

### 4.1.2 Modeling of Growth of Periphyton

The logistic equation, Eq. (1), is used for the governing equation for periphyton growth. It is expected that the parameters $\mu$ and $K$ are the functions of the environmental conditions associated with the periphyton growth. In the present simulation model, the specific growth rate $\mu$ is assumed be a function of solar radiation, water temperature and nutrient concentration, and the environmental capacity $K$ is a function of solar radiation at bed surface:

$$\mu = \mu_{\max} f_I(I_b) f_T(T) f_N(N) \quad (2)$$

$$K = K_{\max} g_I(I_{b0}) \quad (3)$$

in which $\mu_{\max}$ is the maximum specific growth rate, $I_b$ is the daily-averaged solar radiation at river bed, $T$ is the water temperature, $N$ is the nutrient concentration, $K_{\max}$ is the maximum environmental capacity, and $I_{b0}$ is the daily-averaged solar radiation under fair weather at river bed, respectively. The influence functions of solar radiation $f_I$, $g_I$, water temperature $f_T$ and nutrient concentration $f_N$ represent the effects of each environmental factor on specific growth and environmental capacity, and they are expected to take the value between 0 to 1.

The influence functions of solar radiation $f_I(I_b)$ and $g_I(I_{b0})$ are assumed to obey Monod type function:

$$f_I(I_b) = \frac{I_b}{I_{bc} + I_b}, \quad g_I(I_{b0}) = \frac{I_{b0}}{I_{b0c} + I_{b0}} \quad \text{(4a, b)}$$

in which $I_{bc}$ and $I_{b0c}$ are the half-saturated values of solar radiation. The influence function of water temperature is given by the following equation;

$$f_T(T) = \exp\left[\alpha_T \frac{\left(T - T_{opt}\right)^2}{\left(T_c - T_{opt}\right)^2}\right] \quad (5)$$

in which $T_{opt}$ is the optimal water temperature for the growth of periphyton, $\alpha_T$ and $T_c$ is the numerical parameters. The function for nutrient concentration $f_N$ is modeled by Monod type function such as

$$f_N(N) = \frac{N}{N_c + N} \quad (6)$$

in which $N_c$ is the half-saturated value of nutrient concentration.

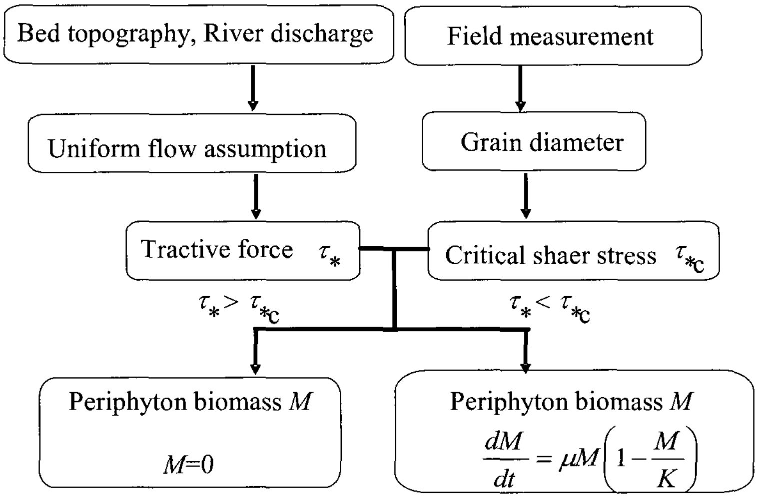


**Fig. 5. Flowchart of the computation**

### 4.1.3 Computational Conditions

The numerical simulation was performed under the conditions of river discharge, water temperature, nutrient concentration and solar radiation measured during June of 2002 and January of 2005. Fig. 6 shows the river discharge during the period. In order to include the effects of grain size distribution of the river bed surface, the bed surface was assumed to be covered by the 5 different grain sizes of sediment, which has the diameter of $d_{10}$= 0.45mm, $d_{30}$= 1.0mm, $d_{50}$=1.5mm, $d_{70}$= 2.5mm and $d_{90}$=4.5mm, respectively. The surface of the river bed was supposed to consist of the sum of 20 % fraction of each grain size sands. The numerical parameters used for the present computation are summarized in Table 2.

## 5. RESULTS OF THE NUMERICAL COMPUTATION

The temporal variation of periphyton biomass calculated during June of 2002 and January of 2005 is depicted in Fig. 7. It was found that the large periphyton growth exceeding 4.0 mg. chl.a/

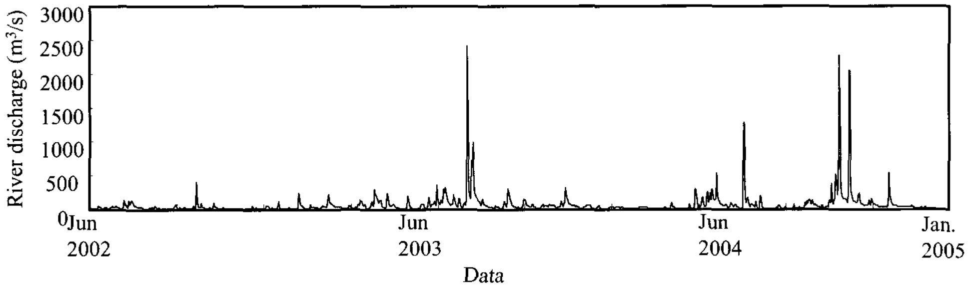


**Fig. 6. River discharge of the computational periods**

**Table 2. Numerical parameters used in the present computation**

| Item | Value | Reference |
|---|---|---|
| $\mu_{\max}$ | 1.1 (day$^{-1}$) | estimated from field data |
| $K_{\max}$ | 38.4(mg.chl.a/m$^2$) | estimated from field data |
| $T_{opt}$ | 18 (°C) | Nozaki et al. (2003) |
| $\alpha_T$ | -2.3 | Ikeda et al. (1998) |
| $T_c$ | 3(°C) | Ikeda et al. (1998) |
| $\delta$ | 0.05 | assumed |
| $\lambda$ | 0.18(m$^{-1}$) | assumed |
| $I_c$ | 5(MJm$^{-2}$day$^{-1}$) | Tashiro (2004) |
| $N_c$ | 0.01(mg.N/l) | Nozaki et al. (2003) |

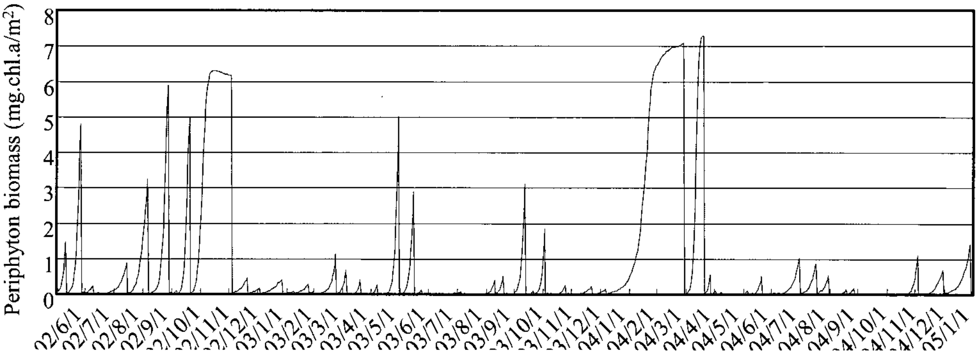
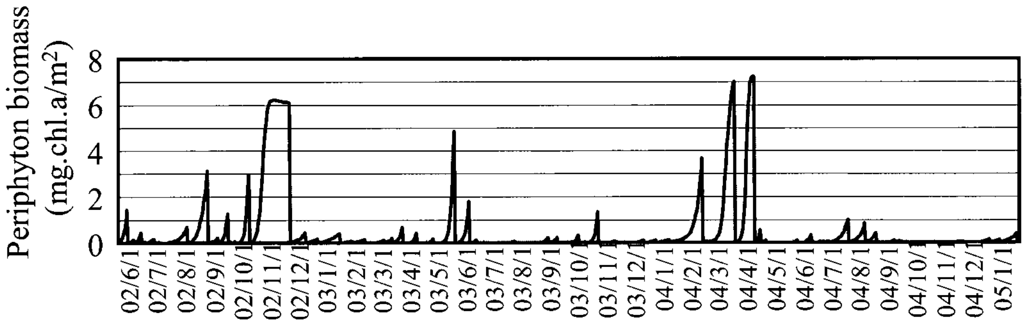


**Fig. 7. Temporal variation of periphyton biomass computed**

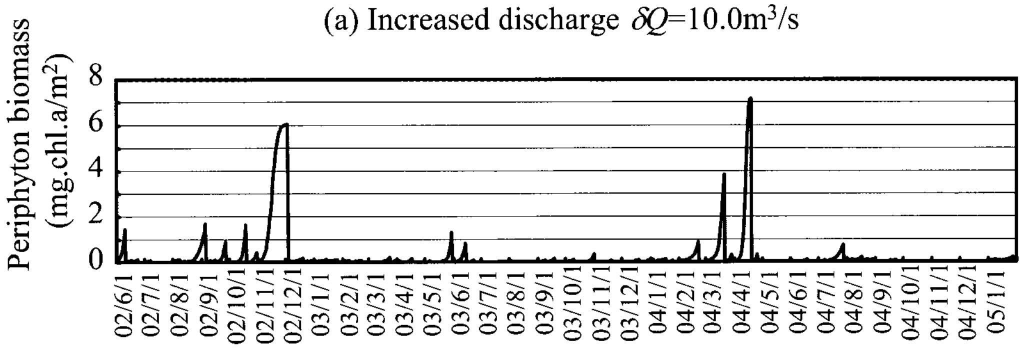
m$^2$ occurs 2 or 3 times/year. Integrating the net production of periphyton biomass during the computational period, the net primary production by periphyton is estimated to be 0.19 mg.chl.a/m$^2$/day. The concentration of chlorophyll a of phytoplankton in the observed river reach varies between 0.5 and 3.0 mg.chl.a/m$^3$, and the rate of primary production of phytoplankton typically takes the value between about 0.3 and 1.0 day$^{-1}$. Multiplying these 2 values, the primary production by phytoplankton is estimated to about 0.15 to 3.0 mg.chl.a/m$^2$/day. This result indicates that the primary production of periphyton is comparable to that of phytoplankton in the observed river.

In order to see the effect of river discharge on the primary production of periphyton, a series of the numerical tests were performed under the various river discharges. Figs. 8(a) to (c) show the temporal variation of periphyton biomass under the different river discharges. It was found that the growth of periphyton decreases with the river discharge, and the primary production approximately becomes 0 for the case that the increased river discharge is 30 $m^3/s$. This increased discharge is equal to the amount of water intake at the observed river during irrigation season. Therefore the growth of periphyton is expected not to be seen at the observed river without the water intake.

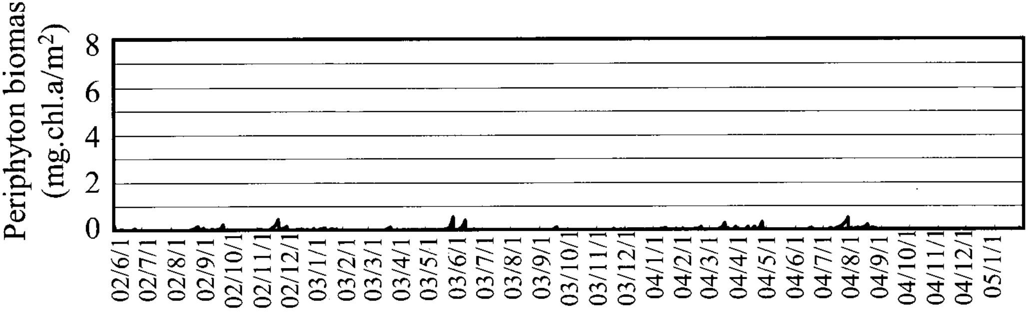
Fig. 9 shows the relation of net primary production to increased river discharge. It was found that the net primary production gradually decreased until the increased river discharge is about 10 $m^3/s$. After that, the net production rapidly decreases with the increased discharge.



(a) Increased discharge $\delta Q=10.0m^3/s$



(b) Increased discharge $\delta Q=20.0m^3/s$



(c) Increased discharge $\delta Q=30.0m^3/s$

**Fig. 8. Temporal variation of periphyton biomass under various discharges**

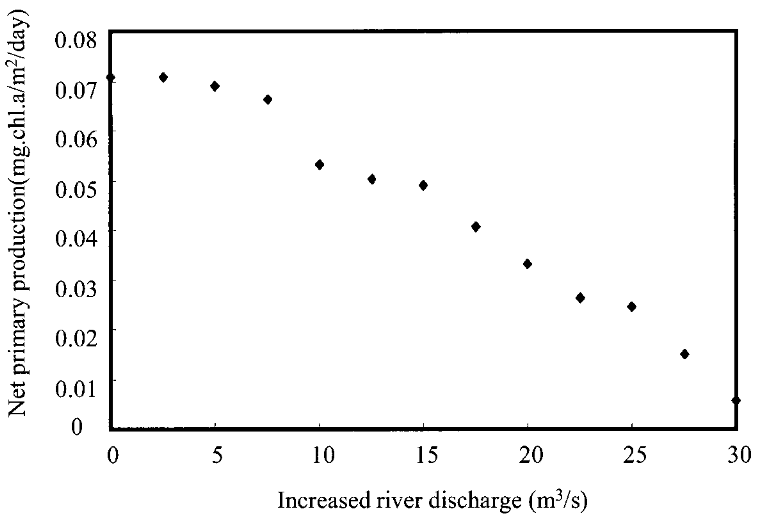


**Fig. 9. Net primary production under different increased discharges**

## 6. CONCLUSIONS

In the present study, the field observation and the numerical simulation were performed to investigate the growth of periphyton in sand river, and the results of the observation and the numerical simulations have revealed the followings;

1) The growth of periphyton occurs even on sand-bed river for the case that the bed materials have not moved.
2) Until the bed materials have not moved, the growth of periphyton is not affected by the grain size of bed materials.
3) The results of the numerical computation show that the amount of net primary production of periphyton becomes comparable that of phytoplankton in river water, and the net production of periphyton decrease with increased river discharge.

These results infer that the reduction of river discharge at ordinary water stage strongly affects the primary productivity of periphyton even in sand river, and the excess intake of river water may induce the increase of primary production in sand river.

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