Development of Potamoplanktonic Diatoms in Downreaches of Japanese Rivers

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Abstract

Occurrence of potamoplanktonic diatoms was recorded in three northeastern Japanese rivers during low discharge in summer: the Omono, the Mogami and the Shinano. The potamoplanktonic diatom communities are characterized by the following:

- 1) universality of appearance of specific species, such as *Cyclotella atomus* and *C. meneghiniana*.
- 2) longitudinal increase in number of living cells along the stream.
- 3) replacement by green or blue-green algae in a lentic environment, such as a river mouth or still waters made by barrage.

The distinction between potamoplanktonic species and exfoliated periphytic species in river waters was clearly based on differences in the living-cell/dead-frustule ratio. Organic carbon/nitrogen ratio of particulate matter in the river water decreased with an increase in chlorophyll *a* concentration passing downstream. Just the opposite was observed in the Tenryu, into which allochthonous limnoplankton flows from eutrophic Lake Suwa.

In the Nagara, potamoplanktonic diatoms occurred each summer during low discharge for three years. One of the causes for the development of potamoplankton is considered to be the increase in flow time related to a change in volume/discharge ratio, which may be enhanced by channeling of the riverbed and widening of the river. River eutrophication by artificial changes in the river environment will be an important consideration in water conservation and use.

Key words: C/N ratio, planktonic diatoms, potamoplankton, river eutrophication

1. Introduction

MURAKAMI *et al.* (1992) observed a longitudinal increase of planktonic diatoms along a stream in the Nagara River, and concluded that it was due to autochthonous production in the main stream. The numerical increase of planktonic diatoms can be attributed to low discharge in summer. In many Japanese rivers, the flow time of river water is delayed near the river mouth in a low precipitation period between the late spring rainy season and the typhoon season. Therefore, the autochthonous

production of planktonic algae should generally occur in these rivers in summer. High water temperature and strong light intensity in summer may enhance the algal production.

In summer 1992, we recorded large standing crops of drift algae in some northeastern Japanese rivers which have long channels through some basins and plain at the foot of mountains. The slope of the riverbed in each river is small in its lower reach. There are neither large impoundments nor lakes to serve as sources of planktonic algae just up from the sampling positions. It is entirely possible that

drift algae in these rivers are autochthonous potamoplankton, as in the Nagara. The object of this paper is to describe flora, biomass and fluctuation of population of the potamoplanktonic diatoms in these Japanese rivers. In addition, we will offer generalizations about characteristics of the potamoplanktonic diatoms based on our observations in northeastern Japanese rivers and in the Nagara over three years. We will also compare drift behavior of allochthonous limnoplankton in the river with that of autochthonous potamoplankton.

2. Description of study area

Five rivers were selected for our present study as shown in Figure 1. The Omono, the Mogami and the Shinano rivers, which are located in northeast Japan, have long channels where they flow through mountains. The

Omono rises from Mt. Daisen and discharged into the Japan Sea through the Yokote Basin and the Akita Plain. The length of the channel is 123km. The slope of the river is about 1/3,200 or less at our sampling positions. The Mogami rises from Mt. Azuma and discharges into the Japan Sea through the Okitama, the Murayama and the Mogami Basins and the Shonai Plain. The length of the channel is 232km. Most of the river banks are farm land. The Shinano has the longest river channel (367km) in Japan. In this study, sampling positions were selected on the Niigata Plain near the river mouth. There is a barrage with sluice gates in the study area in the main channel, but the current was not disturbed since all the gates were opened. Among the other rivers studied, the Nagara was described in our previous paper (MURAKAMI *et al.*, 1992). In the four rivers mentioned above, there

Fig. 1. Sketch map and longitudinal profile of study area. ▼ shows sampling stations.

are neither large reservoirs nor lakes to serve as sources of planktonic algae just up from the sampling stations. In contrast to these rivers, there is a eutrophic lake, Lake Suwa, at the headwaters of the Tenryu. Allochthonous limnoplankton which originate from Lake Suwa is the most dominant component of the drift algal assemblage in this river.

3. Methods

Surface water was taken at each sampling station in the Omono, the Mogami and the Shinano in summer 1992 between the rainy season and the typhoon season. The samplings, especially in the lower rivers, were made at low tide. In the Tenryu, samplings were made in the winter of 1992 when diatoms were the dominant phytoplankton in Lake Suwa. In the Nagara, samples were taken monthly, or more frequently in summer, from March 1990 to December 1992 at Ise Oo-Hashi Bridge near the river mouth at low tide.

Suspended particles were collected on glass fiber filters (Whatman, GF/C). Carbon and nitrogen contents of collected particles were measured using a CHN analyzer. Chlorophyll *a* and pheo-pigment concentrations were determined by the method of LORENZEN (1967).

The method for counting living and dead diatoms was described in detail in our previous paper (MURAKAMI *et al.*, 1992).

4. Results and discussion

4-1. Potamoplanktonic species

Single centric diatoms including *Cyclotella atomus* and *C. meneghiniana* were most dominant in each river except the Tenryu (Table. 1). In the Tenryu, *Stephanodiscus* spp. and *Asterionella formosa*, both originating from Lake Suwa, were dominant. In a word, the dominant diatoms were restricted to a few species ("*Cyclotella meneghiniana* group" including *C. atomus* and *C. meneghiniana*) in the slow flowing rivers. *C. meneghiniana* group is the most frequently recorded potamoplankton in European and American rivers (HUSTEDT, 1957, WAWRIK, 1962, WILLIAMS, 1963, SWALE, 1969, CHIAUDANI and MARCHETTI, 1984, DESCY and

EMPAIN, 1984, EDWARDS and BROOKER, 1984). *Cyclotella meneghiniana* group was also a specific river plankter in Japan judging from our observations on the diatom flora. *Cyclotella meneghiniana* requires a high concentration of silica for growth compared with other planktonic diatoms such as *Asterionella formosa* (TILMAN and KILHAM, 1967). Thus, this species may predominate over other diatoms in a silica-rich river environment, whereas it cannot do so in lakes where silica is sometimes limited by precipitation and consumption (HORI *et al.*, 1969).

In an assemblage of exfoliated periphytic diatoms, dead frustules were frequently observed. In some cases, more than half the periphytic diatom cells in the river waters were empty. Especially among stalked diatoms such as *Cymbella* and *Gomphonema*, living cells were exceedingly scarce. In contrast, more than 90% of the planktonic single centric diatoms were living. Exfoliated periphytic diatoms may not be able to survive and reproduce in running water, which results in a decrease in the living cell ratio of a periphytic assemblage. Otherwise, dead frustules may be more easily exfoliated than living cells from the attached substrata. We consider the drift diatoms with high living-cell/dead-frustule ratios be autochthonous river plankton reproducing in main-stream.

4-2. Longitudinal increase in plankton biomass

Cell numbers of living planktonic diatoms and chlorophyll *a* concentrations increased longitudinally along the stream in the Omono, the Mogami and the Shinano, whereas the cell number of living periphytic diatoms showed no marked increase (Figs. 2, 3 and 4). The increase in chlorophyll *a* concentration must be attributable only to an increase in the number of planktonic diatoms. As mentioned above, there are no lentic waters to serve as sources of planktonic algae just up from our sampling positions in these rivers. The increase in cell numbers is due to production in the main-stream, as was the case in the Nagara (MURAKAMI *et al.*, 1992).

Table 1. Species composition of drift diatoms of the three northeastern Japanese rivers in August 1992.

Figure shows percentage of living cells to total living drift diatom community. Dead frustules shown in parentheses.

distance from river mouth (km)	the Omono		the Mogami		the Shinano	
	upper	lower	upper	lower	upper	lower
	62.2	13.3	43.6	2.8	13.2	3.6
Centrales						
* <i>Aulacosira ambigua</i>				2.3	0.2	0.3
* <i>A. distans</i>		4.9	0.6	0.3	0.8	0.1
* <i>A. granulata</i>		2.9	3.6	0.3		
<i>Melosira varians</i>	1.8	4.9	0.9			
** <i>Chaetoceros</i> sp.				0.4		
* " <i>Cyclotella meneghiniana</i> "	8.2 (2.5)	34.3 (2.9)	71.5 (23.5)	90.7 (31.9)	88.5 (40.4)	94.1 (46.4)
* <i>C. stelligera</i>		4.1 (1.6)	3.6 (3.6)	2.8 (3.6)	0.9 (0.2)	0.2 (1.7)
* <i>Stephanodiscus</i> spp.					0.3 (0.2)	0.1 (0.4)
Pennales						
* <i>Asterionella formosa</i>					1.1	0.3
<i>Fragilaria rumpens</i>	1.8	1.6	1.8	0.2	0.1	
<i>F. ulna</i>	7.3	4.9	1.8		0.1	0.1
<i>F.</i> spp.						
<i>Diatoma hiemale</i>				0.1		
<i>Achnanthes</i> spp.	11.8 (26.9)	4.1 (24.5)	0.6 (7.3)	(13.5)	(4.1)	(5.1)
<i>Cocconeis placentula</i>	(1.8)		(2.6)		(0.2)	(0.5)
<i>Navicula</i> spp.	18.2	7.3	3.0	0.4	0.1	0.1
<i>Cymbella</i> spp.	1.8 (16.8)	(20.0)	0.3 (13.6)	(10.2)	(4.9)	(2.9)
<i>Gomphonema</i> spp.	8.2 (21.1)	0.8 (18.0)	0.3 (13.2)	0.2 (7.9)	(3.8)	(3.9)
<i>Pinnularia</i> spp.	1.8		0.3			
* <i>Nitzschia acicularis</i>		6.5	1.2	0.7	4.6	2.1
<i>Nitzschia</i> spp.	39.1 (30.8)	23.7 (33.1)	10.7 (36.1)	1.5 (32.9)	3.1 (46.2)	2.6 (39.0)

%

* ; freshwater planktonic

** ; marine planktonic

"*C. meneghiniana*" include *C. atoms* and *C. meneghiniana*.

With increases in the number of planktonic diatoms and in chlorophyll *a* concentrations, C/N ratio of the suspended particles in the rivers studied (except for the Tenryu) decreased to between nearly 6 to 7 (Fig. 5), which fits known algal C/N ratios (FLEMING, 1940). In the Tenryu, just the opposite was observed, *i. e.*, chlorophyll *a* concentration decreased longitudinally, and C/N ratio increased passing downstream (Fig.

6), though POC showed no marked decrease. That might be caused by the settling of planktonic diatoms (REIF, 1939, RUTTNER, 1956, HARTMAN and HIMES, 1961), and the adding of allochthonous detritus such as leaf litter which has a high C/N ratio of nearly 10.

In some cases, such as in the Omono and the Mogami, planktonic diatom numbers decreased at the lowest stations near the river mouth.

Fig. 2. Changes in number of living planktonic and periphytic diatoms, chlorophyll *a* and pheo-pigment concentrations, and particulate organic carbon and nitrogen passing downstream in the Omono River on 19 August, 1992.

SCHUCHARDT and SCHIRMER (1991) reported a decrease in the seaward direction of algal biomass in the Weser (Germany). Is the decrease due only to sedimentation, as they suggested? We observed many planktonic diatom frustules on the riverbed just up from the barrage in the Ashida River (MURAKAMI *et al.*, unpublished). The more current velocity decreases, the more diatom cells may settle. But how to explain a decrease in diatom numbers and an increase in chlorophyll *a* concentration in the Omono? In this river, the dominant planktonic diatom *C. meneghiniana* was replaced near the river mouth by *Scenedesmus* spp. (Chlorophyta). A similar replacement of dominant species was recorded just up from Onga-gawa Barrage near the mouth of the Onga (MURAKAMI *et al.*, unpublished). In still water, the number of planktonic diatom cells and chlorophyll *a* concentration both decreased, and blue-green algae appeared. We consider replacement of potamoplanktonic

Fig. 3. Changes in number of living planktonic and periphytic diatoms, chlorophyll *a* and pheo-pigment concentrations, and particulate organic carbon and nitrogen passing downstream in the Mogami River on 18 August, 1992.

diatoms by green or blue-green algae to be caused by competitive exclusion in relation to nutrient concentration, especially silica, and/or the specific sinking rate. We observed a decrease in reactive silica after consumption by diatoms in the impoundments of the barrage in the Onga, and Chikugo (MURAKAMI *et al.*, in preparation). It is possible that there is a longitudinal gradient of silica concentration in the stream where abundant diatom cells are reproducing.

4-3. Seasonal fluctuation of drift algae in the Nagara

We recorded summer algal blooms composed mainly of "*C. meneghiniana*" group in the Nagara in 1990, 1991 and 1992 (Fig. 7). Potamoplanktonic diatoms occurred when low precipitation persisted for two to three weeks in the catchment area. Abundant biomass in the

Fig. 4. Changes in number of living planktonic and periphytic diatoms, chlorophyll *a* and pheo-pigment concentrations, and particulate organic carbon and nitrogen passing downstream in the Shinano River on 1 August, 1992.

Mogami and the Shinano was also recorded under similar conditions. We consider that a delay in flow time resulting from low precipitation causes algal bloom. Algal occurrence each summer must be due to a decreasing flow rate.

4-4. What are "potamoplankton"?

In the absence of a strict definition, MURAKAMI *et al.* (1992) used the term "potamoplankton" to refer to autochthonous river plankters in the Nagara. Based on our observations in the Omono, the Mogami and the Shinano, we generalize the characteristics of potamoplanktonic communities in Japanese rivers to be as follows:

- 1) universality of appearance of specific diatom species
- 2) longitudinal increase in numbers of living cells along the stream
- 3) replacement by blue or blue-green algae in a lentic environment, such as a river mouth or still waters made by barrage.

A few planktonic diatom species are defined as potamoplankton. We consider *Cyclotella atomus* and *C. meneghiniana* as potamoplanktonic diatoms. Potamoplankton certainly occur universally during low discharge in summer in many Japanese rivers.

FUKUSHIMA (1971), reviewing drift algal flora in Japanese rivers, concluded that euplanktonic algae could not reproduce in the mainstream. But in our research, potamoplankton were commonly found in many rivers. Occurrence of potamoplanktonic diatoms may have been overlooked because they are so small (less than $5\mu\text{m}$ in many cases) that they pass through nets. Furthermore, occurrences are limited exclusively to the low precipitation period between the rainy and typhoon seasons. In addition, in some river systems, potamoplankton may have been considered to be allochthonous limnoplankton originating from upper reservoirs and lakes.

4-5. Why do autochthonous potamoplankton occur?

Is it possible that the large biomass of potamoplankton in recent years is related to changes in river conditions? In the lower reach of the Nagara, development of *C. meneghiniana* was not recorded in the 1960s (FUKUSHIMA, 1964).

Fig. 5. Changes in chlorophyll *a* concentration and C/N ratio in the Omono, Mogami, Shinano and Nagara (11 Aug. 1990). Arrows indicate order of sampling stations toward lower river. At lowest sampling station in the Mogami, both chl. *a* concentration and living planktonic diatoms decreased. Chl. *a* concentration and C/N ratio in the Nagara redrawn from MURAKAMI *et al.* (1991).

Fig. 6. Changes in chlorophyll *a* concentration and C/N ratio in the Tenryu. ♦ indicates omitted datum for discussion. This sample contained large amounts of silt originating from sediment.

Increase of nutrient loadings do not seem to be involved, since there is a large excess of nutrients in the Nagara even when diatom bloom occurs (MURAKAMI *et al.*, 1992). We concluded that a delay in the flow time of river water caused algal bloom in the Nagara depending on the seasonal variation of flow rate (MURAKAMI *et al.*, 1992). The flow time may depend not

only on the discharge but also on the volume of a river channel. Channeling in riverbeds may inhibit an exchange of river water, and widening of the river may decrease flow rate. Additionally, the barrage inhibits river flow even if its gates are opened, as seen in the Shinano. River water contains large amounts of nutrients for algal growth; for example, in the Nagara,

Fig. 7. Seasonal fluctuations of chlorophyll *a* at Ise Oo-Hashi Bridge and mean precipitation for 10 days at Gifu City just up from sampling positions in the Nagara.

algal growth potential reached $100\mu\text{g}\cdot\text{l}^{-1}$ in a culture experiment (MURAKAMI *et al.*, unpublished). We consider that artificial changes in the river delay the retention time and cause algal occurrence. River eutrophication by artificial changes in the river environment will pose important problems for water conservation and use.

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摘 要

日本の河川下流部における浮遊珪藻類の発生

夏期の渇水期に、東日本の勾配の緩い河川（雄物川、最上川、信濃川）、及び長良川の下流部に於いて、自生的な浮遊珪藻類の発生を認めた。それらの河川で発生した浮遊珪藻群集は、1) 優占種が少数の種に限定され、それが各河川に普遍的に見られること、2) 下流に向かうに従い、その現存量が増すこと、3) 河口付近では、優占種が緑藻類や藍藻類と交代する場合もあること、等の特徴を持っていた。河川棲浮遊珪藻類の発生は、長良川では、毎年夏の渇水期にのみ発生することが明らかになった。

真の河川棲浮遊珪藻類と認められた種類は、生細胞/死殻比が高く、剥離した付着藻類の流下とは区別できた。また、異所性の浮遊藻類の流下（天竜川）とは、流下に伴うクロロフィル *a* 濃度と C/N 比の変化の様式が異なる事で区別された。

日本の河川は、真の浮遊藻類を欠くとされていたが、夏期の渇水期に限れば、普遍的に河川棲浮

遊珪藻類が発生しているものと判断された。浮遊藻類の発生については、河川容量/流量比が大きくなり、流達日数が長くなることが原因の一つであるが、これには、河川の掘り込みや流路の拡張などの河川改修が影響しているのではないかと考えた。今後、「河川富栄養化」は、水質保全や利水上重要な問題となっている可能性がある。

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