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Suppression of Dinoflagellate Peridinium Bipes Bloom in a Reservoir by Ultraviolet Radiation

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Abstract

The effect of ultraviolet (UV) radiation with a 253.7 nm wave length on the survival of Peridinium bipes was investigated in a laboratory culture system and in a mesocosm placed in a reservoir. According to the results obtained from those experiments, a boat with UV lamps was developed and optimum operating conditions were examined in situ. This boat could treat a maximum of about 700 $m^3 h^{-1}$ of lake water and required 5 hours to treat 2.0 x 10^4 m^2 of surface area of lake water containing 1.0 x 10^3 to 5.0 10^4 P. bipes cells ml^{-1}. The quantity of water treated per hour was 10 times as much as the long hair filtration method which is commonly used.

Introduction

Freshwater red tides of the dinoflagellates Peridinium in reservoirs have been observed in Japan since the 1970's (Nakamoto, 1975; Hata, 1983; Kagawa et al., 1984; Kawabata & Ohta, 1989; Park & Hayashi, 1993). They cause detrioration of scenic value and water quality. However, there is no effective method for suppression of Peridinium blooms because these organisms grow even with little eutrophication. The purpose of this study was to develop equipment for use in suppressing the freshwater red tide of P. bipes in a reservoir. Optimum operating conditions and secondary effects of the UV treatment were also examined.

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Freshwater Red Tide in a Reservoir

The outline of the Tsukabaru Reservoir (N 32° 30', E 131° 18'), Miyazaki Prefecture, Japan (Fig 1), where our survey was carried out, is shown in Table 1. The upstream land area is less than 1% agricultural and about 95% forest. This area contains 4500 people and two upstream reservoirs.

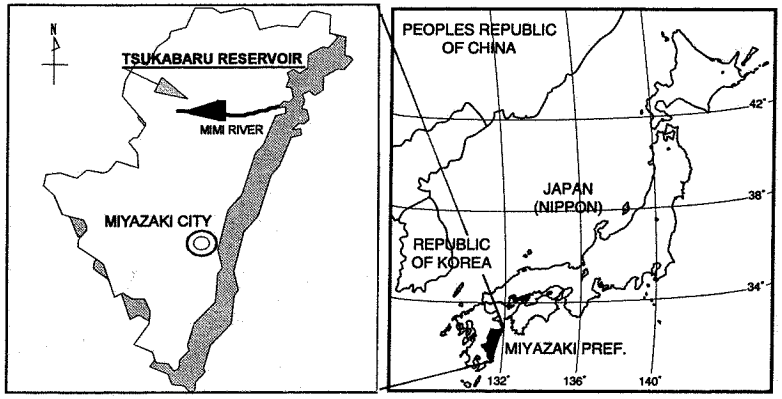

Fig. 1. Location of Tsukabaru Reservoir.

Table 1. Outline of the reservoir.

Item	Specification
Reservoir	
Catchment area	416.6 km2
Total capacity	34,326,000 m3
Effective capacity	19,555,000 m3
Water surface area	1.14 km2
Mean depth	26.01 m
Length	8600 m
Annual inflow	1.37 x 10^9 m3
Turn over rate	40 times year-1
Elevation	235.5 m
Power Station	
Maximum power discharge	73.8 m3 sec-1
Maximum power output	62.6 MW
Dam	
Type	Concrete gravity
Year constructed	1938
Crest length x height	215 m x 87 m

Freshwater red tide has been observed since the late 1970's in this reservoir. It has been recently observed every year that freshwater red tide appeared first at the head of the reservoir in both spring and autumn and it later spread downstream. The dominant species of the bloom was the dinoflagellate Peridinium bipes. No toxicity was reported for this species.

Water quality, which is expressed by the mean values of several points in the reservoir in 1991, was as follows: total nitrogen; 232 μg l^{-1}, phospohorus; 17 μg l^{-1}, and COD; 0.9 mg l^{-1}.

Effect of Ultraviolet Radiation on the Survival of Peridinium Bipes

To develop equipment for use in supressing the bloom of P. bipes in the reservoir, first, the effect of UV radiation on the survival of P. bipes was investigated both in a laboratory culture system (Kawabata, et al., 1990) and in a mesocosm in situ (Kawabata, et al., 1991).

Laboratory experiment

The water sample was taken from the reservoir. It contained only Peridinium bipes when examined microscopically and the population density was 3.6 x 10^4 ml^{-1}. Almost all the cells were moving actively. Fifty ml of the sample was dispensed into petridishes 85mm in diameter. The petridishes were placed under UV lamps (GL-15, Toshiba Co., Ltd, Japan) which emitted 253.7 nm. The strength of UV radiation was adjusted by placing petridishes at different distances from the UV lamp. The intensity of UV radiation was measured by a radiometer (Model UVX Digital Radiometer, UVP Inc., USA). The culture was carried out under continuous illumination of 3000 lux by fluorescent lamp (FL 40 SD, NEC Co., Ltd, Japan) and at a temperature of 15 °C.

The changes in the number of dead cells were surveyed at certain periods of during continuous UV radiation until all the cells died. After mixing the sample well in a petridish, one ml of the sample was transferred into a counting chamber and all the live and dead cells were counted microscopically by the method of Satoh and Yamaguchi (1988). The death rate was expressed by the ratio of dead cells to the total cells. The number of dead cells were obtained by subtraction of the number of dead cells of the control experiments without UV radiation from those of each experiment.

The time required for either 50% of or all live cells to die under each strength of continuous UV radiation conformed to a hyperbolic relation with the

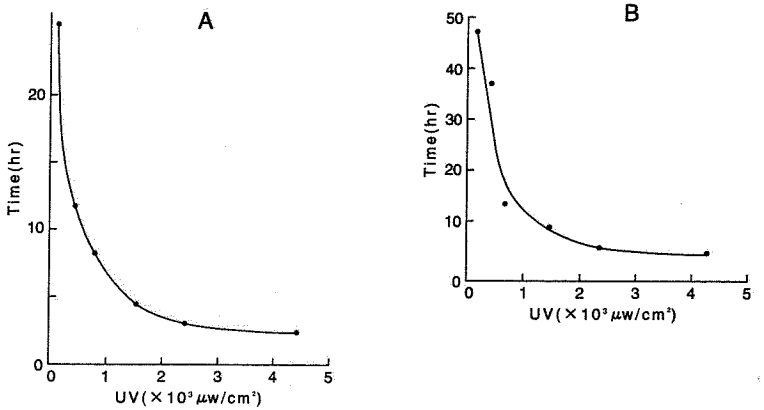

Fig. 2. The time for 50% of the cells (A) and all the cells (B) to die under each strength of continuous UV radiation.

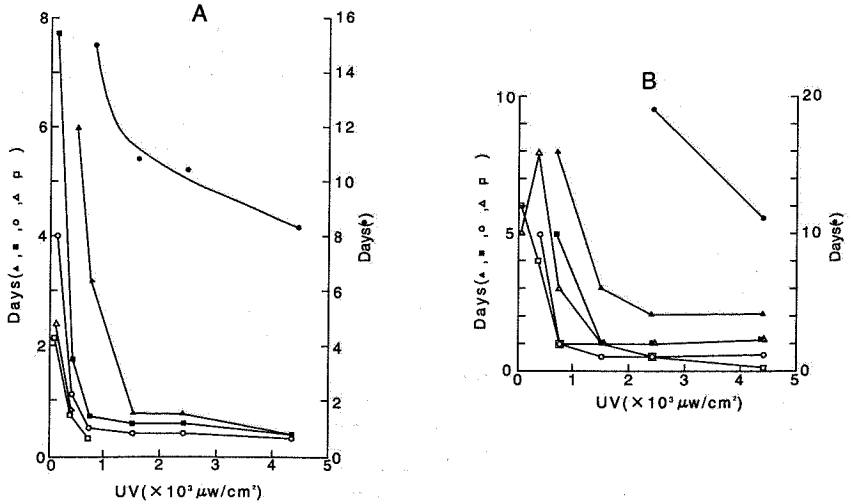

Fig. 3. The time for 50% of the cells (A) and all the cells (B) to die after the end of a certain period (●; 1min, ▲;15min, ■;30 min, ○;1 hr, △;2 hr, □;5 hr) of each strength of UV radiation.

strength of UV radiation, i.e., all live cells died within 6 hrs and 48 hrs under UV radiation greater than 2400 and 80 uW cm^{-2}, respectively (Fig. 2). Therefore, energy consumption of UV is proportional to the strength of UV radiation. The relationship between the strength of UV radiation and the time required for either 50% or all live cells to die after the end of different periods of UV radiation was also described by hyperbolic curves except in the case of one min radiation, i. e., all the cells were killed by UV radiation of 80 uW cm^{-2} for longer than 2 hr and 2400 uW cm^{-2} for longer than 1 min within 6 and 19 days, respectively (Fig. 3). The energy to produce UV radiation to kill all the live cells was 2400 uW cm^{-2} for one min.

Mesocosm experiment

A mesocosm was installed in the reservoir by enclosing the surface water column (75.2 m^3) containing P. bipes. The mesocosm, made of waterproof canvas, was 4m long, 4m wide, 5m deep (Fig. 4). In the mesocosm, an UV lamp (GL90SH, Sankyo Denki Co., Ltd. Japan), 123 cm long with an output power of 30W emitting 253.7 nm light, was fixed vertically under the water surface. Aeration was conducted at the lower end of the UV lamps at 5 liters per minute. A control experiment was carried out in the mesocosm without an UV lamp. Samples were taken at 7 points at each depth; 0.1m, 2.0m and 4.5m depth, with a one-liter Heyroht sampler. The seven samples were mixed at a certain depth and used for counting the cells. Values were expressed by mean values per mesocosm. They were calculated by the summation of the value at 0.1m depth multiplied by 0.2, at 2.0m depth by 0.4, and 4.5m depth by 0.2. One ml of the sample was transferred into a counting chamber. All the moving cells, non-moving cells and dead cells were counted under a phased microscope. Discrimination of dead cells from non-moving cells was done according to apparently destroyed cytoplasm.

Intensity of UV in the mesocosm decreased proportionally with distance (Fig. 5). This indicated that vertially proportional attenuation in UV intensity would be observed when the UV lamp is installed horizontally. The bloom of P. bipes in the mesocosm disappeared because of water circulation when aeration began. Changes in the numbers of moving, non-moving and dead cells are in Fig. 6. Almost all live cells were disappered from the water within 2 days. No moving cells were observed for 15 days after the experiment in the mesocosm which was left without UV radiation. In the reservoir where this experiment was carried out, the bloom of P. bipes is usually observed in the upper area of 4.2 x 10^4 m^2. Assuming that UV radiation using a UV

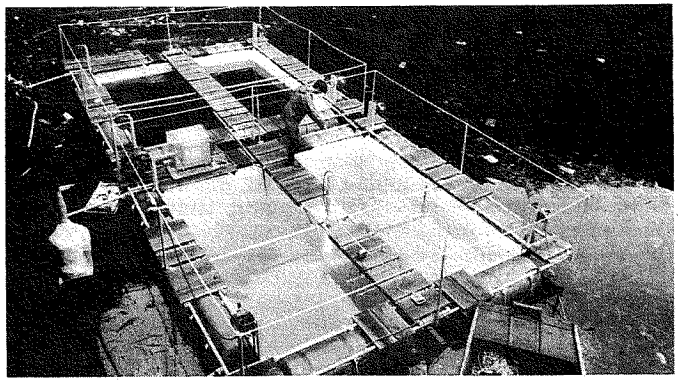

Fig. 4. Mesocosms in the reservoir.

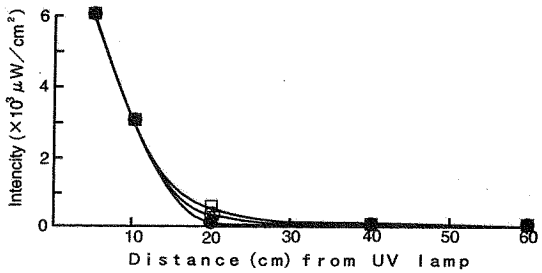

Fig. 5. Intensity of UV in the mesocosm.

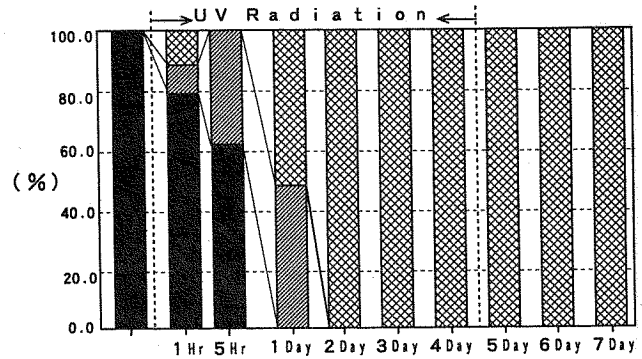

Fig. 6. Changes in numbers of moving (■), non-moving (▨), and dead cells (▩) in the mesocosm.

lamp is enough to kill all live cells in 4 x 4 m^2 for 2 days and that the UV lamp is moved to adjacent areas after each treatment, it was estimated that a continuous UV radiation for 28 days using 200 UV lamps is required to suppress the bloom.

Development of a Boat Equipped with UV Lamps for Suppression of the Bloom

In order to evaluate the feasibility of UV radiation in situ, a boat equipped with UV lamps was developed and optimum operating conditions were examined (Iseri et al., 1993). The exterior appearance of the UV boat is shown in Fig. 7. A schematic diagram of the UV boat is shown in Fig. 8. The length and width of the boat were 10.3 m and 3.6 m, respectively. The UV boat consisted of two trunks, 0.6 m in diameter. Inside each pipe, 20 UV lamps with an emission intensity of 253.7 nm and with 30W (SC9001S, Sankyo Electric Co.) were installed. The number of UV lamps was determined according to the results described above so as to supply the minimum energy (2400uW cm^{-2}). Optimum time of exposure was automatically calculated depending on the cell concentration which was obtained by measuring turbidity, and by regulating the speed of rotation of the motor which served to direct the lake water into the UV pipes.

UV radiation for over 20 seconds was enough to kill 100% of the cells of the freshwater red tide when the concentration was less than 5.0 x 10^3 ml^{-1} while over 50 seconds were required to kill 90% of the cells when the concentration was more than 1.0 x 10^4 cells ml^{-1}. Optimal velocity of the lake water in the pipes was regulated automatically between 17 to 35 cm sec^{-1} depending on the cell density ranging between 2.0 x 10^3 to 2.3 x 10^4 cells ml^{-1} to kill 99% of the total cells. This boat could treat a maximum of about 700 m^3 h^{-1} of lake water and required 5 hours to treat 2.0 x 10^4 m^2 of surface area of lake water containing 1.0 x 10^3 to 5.0 x 10^4 P. bipes cells ml^{-1}. The quantity of water treated per hour was 10 times as much as the commonly used long hair filtration method.

Conclusion

A boat equipped with UV lamps was effective in suppressing the bloom of P. bipes in upstream of a reservoir with little effect on the nitrogen and phosphorus loading into the reservoir.

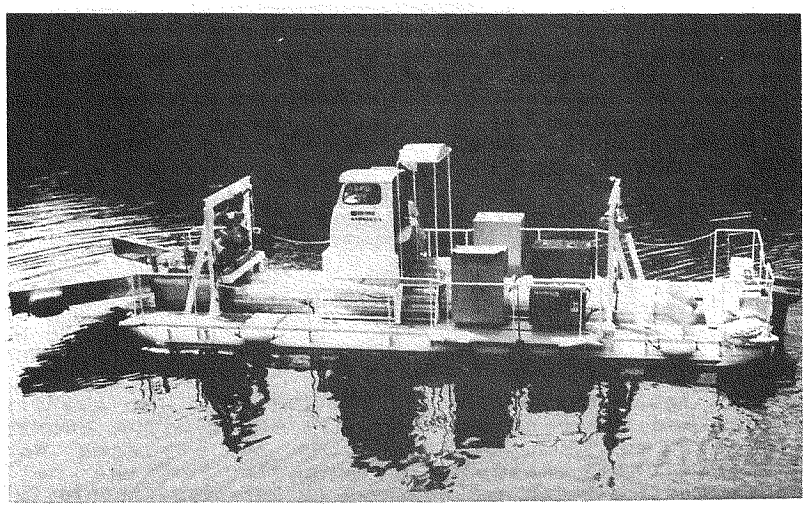

Fig. 7. The UV boat.

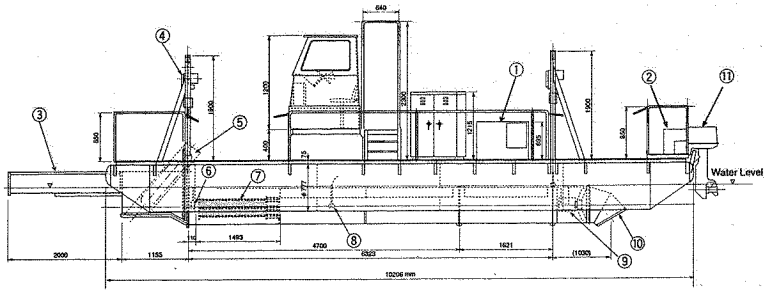

Fig. 8. Shematic diagram of the UV boat. (1); Electric generator, (2); Fuel tank, (3); Intake mouth, (4); Crane, (5);Screen, (6); Turbidity meter, (7); UV lamps, (8); Geomagnet electro-current meter, (9); Engine, (10); Outlet mouth.

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