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A Study on the *Gymnodinium nagasakiense* Red-Tide in Jinhae Bay of Korea

Lee, Jin Hwan and Hi-Sang Kwak*

(Dept. of Biology, Sangmyung Women's University, Korea Ocean Research and Development Institute)*

鎭海灣의 *Gymnodinium nagasakiense* 赤潮에 관한 硏究

李 晋 煥・郭 熙 相*

(祥明女子大學 生物學科・海洋硏究所*)

ABSTRACT

Relationship between the causative organisms of red-tide and environmental factors had been ecologically dealt with. The surveys were conducted at seven stations in Jinhae Bay from July to September 1981. The water temperature and salinity had wide range, *i. e.* 23.3~29.3°C and 19.78~31.29‰, but several chemical factors remarkably fluctuated; dissolved oxygen 102.9~210.4 %, COD 2.10~8.96mgO_2/l, pH 8.1~9.4, NO_3-N trace~1,052μg/l, PO_4-P 0.6~58.9μg/l and chlorophyll-*a* 2.18~290.5mg/m^3 in the observed area. The red-tide was mainly caused by two dinoflagellate taxa throughout major outbreaks occurred in July through September. Leading species of red-tide were *Gymnodinium nagasakiense* belong to the major species and *Prorocentrum micans, P. minimum, P. triestinum* as minor species. During the surveyed period, cell numbers of the causative organisms of the red-tide extensively varied from 3×10^4 cells/l to 1.5×10^7 cells/l with months and stations; *Prorocentrum* spp. 0.3~12.5×10^5 cells/l in July; *Gymnodinium nagasakiense* 0.2~5.9×10^6 cells/l, 1.1~4.7×10^6 cells/l, and 0.2~15.1×10^6 cells/l in July, August, and September, respectively. *Gymnodinium nagasakiense* red-tide seemed to be caused by the high water temperature in summer, unusually low salinity due to heavy rains, and the concentrated nutrients for phytoplankton supplied with the municipal sewages from the urban areas and the wastewaters from the industrial complexes.

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INTRODUCTION

Large-scale red-tides due to *Gymnodinium* species had occurred for the first time in Omura Bay of Japan in 1965 (Iizuka and Irie, 1966). Lee *et al.* (1981*a*) had newly recorded the distribution of this species in Jinhae Bay located on the southern coast of Korea. During the summer in 1981 and 1982 huge red-tides were caused by *Gymnodinium* species and damaged to the various aquatic products (Cho, 1981; Park, 1982). Yoo(1984) studied on the population dynamics of red-tide organisms in the coastal waters of Korea. Among them, *Gymnodinium* species had been also reported on the abundant occurrence during the periods from June to October in 1981 and 1982.

The purpose of this paper is ecologically to study on the *Gymnodinium nagasakiense* red-tide occurred during the periods from July to September 1981 in Jinhae Bay.

STUDY AREAS

The proposed Jinhae Bay is located in the southern part of Korea (Fig. 1). The Bay, which is adjacent to Masan, Changwon, and Jinhae cities, is well protected by Geoje Island and encircled land mass. The topography of the Bay is largely divided into three embayments of the Masan, Haengam, and Jindong Bay.

Until the 1960's, there were many aquacultural activities such as oyster beds, laver farms, hard-shelled mussel fields *etc.* scattered around this Bay. During the last two decades, industrialization and urbanization had been taken place very rapidly in Korea, accompanied by an alarming increases in deterioration of quality of coastal waters, especially near the large cities and the near-sea industrial complexes. The total input, into the surveyed area from municipal effluents for the pollution, was equivalent to 500,000 people and the main point sources of the pollution were the above cities scattered around the coastal zone of Masan and Jinhae areas. Therefore, the proposed Bay had been directly or indirectly influenced by the discharge of fully or partially treated wastewaters from the industrial complexes and sewages from the urban area. In recent years, biological phenomena in the basin such as plankton blooms and red-tides appeared increasingly at frequent intervals and were intensified mainly due to ever-increased industrial activities in the towns and cities surrounding this Bay.

The area of the stations 1, 2, and 3 was named Masan Bay because of the Masan area at the inner harbour of the Jinhae Bay near Masan and Changwon cities, the station 4 was Haengam Bay because of being adjacent to Jinhae City and Jinhae Chemical Co. (fertilizer plant), and the area of stations 5, 6, and 7 Jindong Bay, where was important for the marine aquaculture grounds.

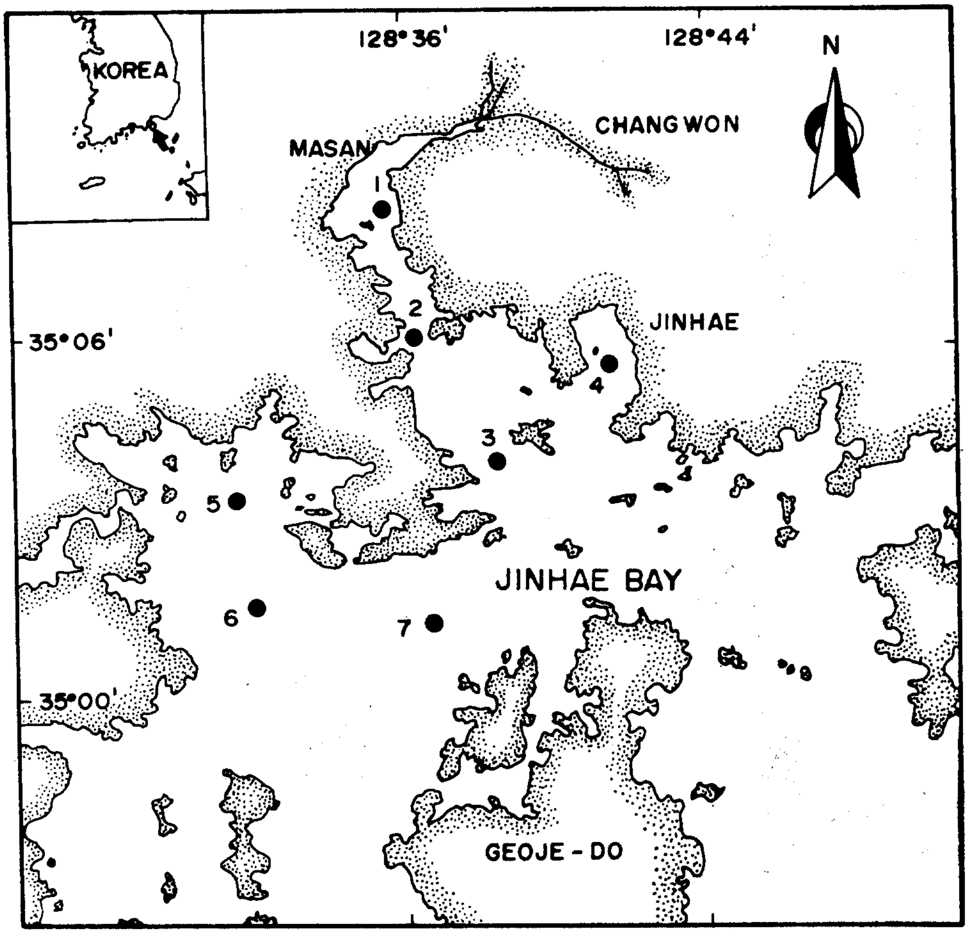

Fig.1. Sampling stations in jinhae Bay.

GYMNODINIUM NAGASAKIENSE AS MATERIAL

The nomenclature of this species had not been officially termed until 1975. This species had been called by the various tentative names during the period of fifteen years from 1966 to 1981 in Japan, for example, *Gymnodinium* sp. (Iizuka and Irie, 1966), *Gymnodinium* sp. 1 (Adachi, 1972), and *Gymnodinium* '65-type (Iizuka, 1972, 1976, 1979; Iizuka and Irie, 1969; Hirayama and Numaguchi, 1972; Hirayama *et al.*, 1972; Numaguchi and Hirayama, 1972; Takayama, 1981). However, Iizuka and Nakajima(1975) had made an attempt to give a name of *Gymnodinium nagasaki* and one of the other authorities tentatively selected the name *Gymnodinium nagasakii*. Takayama and Adachi(1984) had described the morphological characters of this species and they had given a new taxonomical name of the *Gymnodinium* *nagasakiense* according to the rules of International Code of Botanical Nomenclature.

METHODS

Measurements of physicochemical factors Temperature and dissolved oxygen contents in seawater were measured *in situ* using Dissolved Oxygen Meter (YSI Model 57). Temperature was then calibrated with U.S. NBS-certified thermometer and saturation percentages of dissolved oxygen were computed from dissolved oxygen contents using Weiss's tables (Weiss, 1970). Salinity was determined by Inductively Coupled Salinometer (601Mk1V). The pH determination was carried out *in situ* by using pH meter (Orion Model 407 A/F). The transparency was detected using secchi disc in meter. Chemical oxygen demands(COD), nitrate-nitrogen, phosphate-phosphorus and chlorophyll-*a* were determined according to Strickland and Parsons(1972).

Phytoplankton sampling Phytoplankton samples were collected using a van Dorn water sampler and preserved with Lugol's solution at the selected seven stations during the period from July to September in 1981. In laboratory the settling method was adopted for both quantitative and qualitative analyses. From each sample a well-mixed aliquot (1*ml*) was then transferred to a slide and all of the species were identified. Cell counting for phytoplankton was performed in the Sedgwick-Rafter Counting Chamber and the sum of the counts were calculated and expressed for the phytoplankton standing crops in cells/*l*.

RESULTS

Comparison of detected characteristics with 3 Bay The comparisons of physicochemical and biological parameters in these observed areas were shown in Table 1 with those of europhicated seawaters (Yoshida, 1973). The mean transparencies were the shortest in Masan Bay with 1.0m in depth, and 2.0m in Haengam and Jindong Bay. The mean values of the chemical oxygen demands(COD) were 5.62, 4.23, and 4.95mgO_2/*l* in the surface water of Masan, Haengam, and Jindong Bay, respectively. The dissolved nitrate-nitrogen concentrations of surface apparently varied with different order of values in each Bay. The average in Masan Bay was about 3 and 12 times as high as those in Haengam and Jingdong Bay, respectively. On the other hand, it was interested to note that the phosphate-phosphorus concentrations of surface in Haengam Bay was exceeded far more than those of Masan Bay. pH in most stations got over 8.6. Saturations of dissolved oxygen in surface were definitely different from those of bottom. All of the saturations in the surface water were supersaturated, but those of the bottom were unsaturated. The monthly mean values of chlorophyll-*a* were about 40, 10, and 47mg/m^3

Table 1. The average characteristics of physicochemical and biological parameters in surface water compared with eutrophicated seawaters in Jinhae Bay of Korea during the summer (July~Sept.) in 1981

Parameters	*E.S.	Stations: 1, 2, 3(Masan Bay)				4(Haengam Bay)				5, 6, 7(Jindong Bay)			
		July	Aug.	Sept.	mean	July	Aug.	Sept.	mean	July	Aug.	Sept.	mean
Transparency(m)	3~10	1.0	1.5	1.0	1.0	3.0	1.0	1.5	2.0	3.5	1.5	1.5	2.0
C.O.D.(mgO_2/l)	1~3	4.6	7.5	4.8	5.6	2.8	4.5	5.4	4.2	3.3	6.6	5.0	5.0
NO_3-N($\mu gN/l$)	24~140[a]	613.7	785.0	342.3	580.3	93.0	nd	310.0	201.5	17.0	nd	122.3	69.7
PO_4-P($\mu gN/l$)	30~100[b]	19.9	31.2	44.4	31.8	35.4	71.6	35.8	47.6	4.1	25.1	27.3	18.8
pH	—	9.3	8.4	8.2	8.6	8.6	8.4	8.7	8.6	8.7	9.0	8.6	8.8
Saturation of D.O.(%)	S : 100	179.6	179.9	151.5	170.3	102.9	210.4	162.3	158.5	130.7	171.0	156.4	152.7
	B : 30~80	26.7	10.0	41.4	26.0	75.3	10.2	60.0	48.5	86.9	30.0	59.4	58.8
Chl.-*a*(mg/m^3)	1~30	27.0	31.9	61.5	40.1	2.5	17.3	9.3	9.7	5.4	114.3	22.0	47.2

* Eutrophicated seawater (Yoshida, 1973)
a : Inorganic N, b : Total phosphorus, S : Surface water, B : Bottom water, nd : non-detected

in Masan, Haengam, and Jindong Bay, respectively.

Environmental conditions during red-tide Environmental conditions during *Gymnodinium nagasakiense* red-tide were presented in Table 2. Seawater temperature of surface ranged from 23.3°C at station 5 in September to 29.3°C at stations 2 and 5 in August, 1981. Monthly variations of water temperature were 23.7~26.1°C in July, 28.2~29.3°C in August, and 23.3~25.3°C in September. Salinity of surface water extremely varied from 19.78‰ at station 4 in September to 31.29‰ at station 7 in August. Salinity pattern did not coincide with the months or with the areas. The mean values of salinity variations in July and August were 29.33‰ and 30.56‰ , respectively. In September, due to heavy rain-fall, salinities from the whole surface water ranged from 19.78 to 22.48‰ which was less than those of July and August. Saturations of dissolved oxygen in surface water were supersaturated at all of the observed stations during the surveyed period. The monthly mean saturation percentages of dissolved oxygen were 133.6% in July, 191.9% in August, and 171.7% in September. The COD from surface water ranged from 2.10mgO_2/l at station 6 in July to 8.96mgO_2/l at station 2 in August. The monthly mean COD levels were 3.29, 6.62, and 5.21mgO_2/l in July, August, and September, respectively. The COD values of surface water mostly exceeded 5.0mgO_2/l at all of the surveyed stations in August and September, 1981. The pH values during the period ranged widely in surface water from 8.1 at station 2 in August and September to 9.4 at stations 6 in August. The monthly mean pH values for the surface were 8.83 in July, 8.69 in August, and 8.48 in September. Extremely high values of pH were observed in the period.

Nitrate-nitrogen concentrations in surface water varied from non-detectable levels at station 5 in July and at stations 3, 4, 5, 6, and 7 in August to 1,052$\mu g/l$ at station 2 in Jinhae Bay on August 1981. July and September samples showed the mean values of nitrate-nitrogen with 63.7$\mu g/l$ and 119.0$\mu g/l$, respectively. Particularly the maximum nitrate-nitrogen concentration was surprisingly 1,052$\mu g/l$ at station 2, but at the other stations nitrogen contents in surface were not detected in August. Phosphate-phosphorus concentrations of surface water ranged from 0.6 $\mu g/l$ at station 6 in July to 71.6$\mu g/l$ at station 4 in August. In August the mean phosphate-phosphorus concentration was around 37$\mu g/l$ and similar to in September, but that of July was low level of 22.93$\mu g/l$.

Monthly variations of *G. nagasakiense* cell number from the surface varied with months and ranged from non-appearance of the cells at station 1 in July and August to the maximum 1.5×10^7 cells/l at station 6 in August 1981. As shown in Table 3, the maximum cell number of *G. nagasakiense* was observed at station 3 with 5.9×10^6 cells/l in July, while they appeared less than 10^5 cells/l from the neighbour stations 1, 2, and 7. The *G. nagasakiense* also appeared to be as high as hemical factors of

NO_3-N (μgN/*l*)	PO_4-P (μgP/*l*)	Chl.-*a* (mg/m³)
92	44.7	29.90
93	35.4	2.54
nd	11.0	6.51
6	0.6	3.07
1,052	52.1	49.16
nd	12.2	27.70
nd	71.6	17.26
nd	12.2	2.18
nd	58.9	72.56
nd	17.5	290.46
56	58.9	75.15
54	57.6	94.22
310	35.8	9.33
158	9.4	20.34
17	23.1	25.96

5.7×10^5, 2.0×10^5, and 1.6×10^5 cells/l at station 4, 5, and 6, respectively, in the surface water of July. In August, the highest *G. nagasakiense* value with 1.5×10^7 cells/l in the surface was obtained at station 6 and, at the other stations, the cell number appeared to be almost similar to the values of $1 \sim 5 \times 10^6$ cells/l except at station 1. The *G. nagasakiense* was not occurred even though at the same station 1 in July. In September, on the other hand, a plenty of *G. nagasakiense* with 2.1×10^6 cells/l was counted from the surface of station 1 where was located in the central part of the Masan Bay as well as station 2 with 2.8×10^6 cells/l, and as station 4 with 2.3×10^6 cells/l in the Haengam Bay. Cell number of *G. nagasakiense* with 8.3×10^5 cells/l and 2.2×10^5 cells/l at both stations 5 and 6 appeared, but quite low at station 3 and 7.

Table 3. Variations of the *Gymnodinium nagasakiense* cell number during the periods from July to September 1981

Month	Stations						
	1	2	3	4	5	6	7
July 1981	—	36,540	5,941,183	201,020	568,820	157,777	8,784
Aug.	—	1,075,000	2,752,238	3,138,746	3,017,210	15,145,659	4,690,450
Sept.	2,096,436	2,838,860	69,776	2,346,566	826,798	224,013	4,446

Among the phytoplankton communities observed, the causative organisms for red-tide except *Gymnodinium nagasakiense* were minor species, *i. e.*, *Prorocentrum micans*, *P. minimum*, and *P. triestinum*. In July, cell number of *Prorocentrum* spp. in the surface varied extensively with the surveyed Areas, ranging from $0.32 \sim 2.31 \times 10^5$ cells/l in Jindong Bay to $1.25 \sim 1.32 \times 10^6$ cells/l in Masan Area (Lee *et al.*, 1981*b*). It was very remarkable that *Prorocentrum* spp. in the surface water had shown the values less than 10^5 cells/l at almost all of the stations in August and September, but it was recorded as 1.26×10^6 cells/l at station 1 in the same period of August (Lee *et al.*, 1981*b*).

The causative organisms were distributed in surface waters with heavy densities with months and observed areas (Cho, 1981; Lee *et al.*, 1982; Park, 1982; Yoo, 1984). The color of the surface waters was generally brown in patches (Cho, 1981). Such heavy red-tide had not been ever seen in the Korean coastal waters (Cho, 1981; Lee *et al.*, 1982; Park, 1982). Furthermore, damages for aquatic products due to the red-tide were estimated to be 1.7 billion Won from Jinhae Bay in 1981, and were equivalent to US$2.25 million (Cho, 1981).

DISCUSSION AND CONCLUSION

Nutrients were concentrated on very high value in the surface water of Jinhae

Bay, especially nitrogen, phosphorus, and the other chemicals, and they had been gradually accumulated every year (Lee *et al.*, 1981*b*, 1982, 1983). *Gymnodinium* '65-type occurred in Omura Bay of Japan was found for the first time in Jinhae Bay, the south coast of Korea (Lee *et al.*, 1980). Thereafter, the species had been observed in ever summer in this Bay according to Lee *et al.* (1981*b*). From July to September in 1981, large scale red-tides were caused by *Gymnodinium nagasakiense* in the whole area of this Bay (Cho, 1981).

As shown in Table 2, water temperature acted as one of the important environmental factors during the surveyed period. Adachi(1972) also pointed out the high water temperature for growth of *Gymnodinium* sp. 1. *Gymnodinium* '65-type occurred intensively at the high water temperature in early and middle of August 1966 in Omura Bay, but its occurrence was not enough to be cause of the red-tide (Iizuka and Irie, 1969). Low salinity after heavy rainfall was also one of the important factor. The large amount of freshwater influx was attributed to the heavy rainfall in the middle and the end of July in this area (C.M.O., 1981). Numaguchi and Hirayama(1972) obtained the suitable chlorinity 11.0～18.5‰ for the growth of *Gymnodinium* '65-type. The red-tide by the *Gymnodinium* '65-type was associated with the inflow of freshwater in rainy seasons (Iizuka and Irie, 1969; Iizuka, 1972).

Saturation percentage of dissolved oxygen was all supersaturated in surface water during the surveyed period in Jinhae Bay 1981. This may be a result from intensive oxygen production due to the outburst of *Gymnodinium nagasakiense* and the other phytoplankton cells. The COD in the coastal waters near the municipal or industrial areas was likely enough to be controlled by one or both of two factors; municipal sewages and industrial waste-waters. In the central part of the Masan and Haengam Area, the control factor for COD in surface water seemed to be the former, and at Jindong Area the latter seemed to be important. In previous works, COD values were 1.26mgO_2/l in 1974 (Lee *et al.*, 1974), 1.92mgO_2/l in 1977 (Chung *et al.*, 1977), and 2.23mgO_2/l during the period from 1979 to 1980 (Lee *et al.*, 1980) in the surface of this area. Furthermore, COD levels were exceeded 3mgO_2/l, which were the limit for the hypereutrophic state (Yoshida, 1973), in the almost whole surface areas during the surveyed period. Numaguchi and Hirayama(1972) reported the suitable pH value of 7.8 for red-tide, but extremely higher values of pH were resulted from the primary production in this area. Adachi(1972) also explained that high levels of pH was a result from prosperous phytoplankton photosynthesis. During the period of three months under the red-tide by *Gymnodinium nagasakiense*, it was very interested in the variations of the dissolved nitrate-nitrogen concentration in this area. The dissolved nitrate-nitrogen concentrations were strangely not to be detectable in August except station 2, while these values were changefully measured in July and September. Hirayama *et al.* (1972) mentioned that, in order to find the limiting factors for the growth of the red-tide organisms *Gymnodinium* '65-type, the supply of inorganic nutrients into the sea water was essential to the outbreak of red-tide by this species. Iizuka(1976) studied on the succession of red-tide organisms resulted from the condition of water pollution. According to his results, the outburst of *Gymnodinium* population was mainly caused by water pollution from land. There were many case studies on the seawater pollution in this Bay (Lee *et al.*, 1980, 1981*a*, 1982, 1983). The red-tides could be derived from the pollutant inflow due to heavy rain-fall in these seasons. In the surface water of Masan Area, it was considered as consumption by the outburst of *Gymnodinium nagasakiense* that the dissolved nitrate-nitrogen could not be detected in August. But the nitrate-nitrogen content was the highest in the surface water of station 2 in August, and it indicated the continuous inflow of the freshwater, sewages, and industrial wastewaters from Masan and Changwon area.

The high phosphate-phosphorus concentration in the surface during the surveyed period was always observed at station 4 named Haengam Area. It could be thought of a result from the wastewaters of fertilizer plant, the Jinhae Chemical Co.(Park, 1975; Cho, 1978; Lee *et al.*, 1981*a*). The high phosphate-phosphorus concentrations in all of the stations, therefore, could be regarded as an effect by the current diffusion. Solorzano and Strickland(1969) indicated that the phytoplankton could polymerize the polyphosphate from the *o*-phosphate and take it in the storage pool for the source of phosphorus. According to this idea, the dissolved phosphate-phosphorus was not used directly to make the red-tide up.

摘 要

本 硏究는 1981年 7月부터 9月까지 鎭海灣의 7個 定點에서 植物플랑크톤 渦鞭毛藻類인 *Gymnodinium nagasakiense*에 의한 赤潮現象에 대하여 生態學的으로 究明하였다.

調査期間 중 物理·化學的 環境要因의 變化는 水溫이 23.3～29.3°C, 鹽分 19.78～31.29‰, 溶存酸素 飽和度 102.9～210.4%, COD 2.10～8.96mgO_2/l, pH 8.1～9.4, 窒酸鹽——窒素 trace～1,052μg/l, 燐酸鹽——燐 0.6～58.9μg/l, 그리고 chlorophyll-*a*는 2.18～290.46mg/m^3의 범위를 나타내었다.

赤潮原因生物은 渦鞭毛藻類인 *Prorocentrum micans*, *P. minimum*, *P. triestinum*, 및 *Gymnodinium nagasakiense*였고, 7월에는 *Prorocentrum* spp.와 *G. nagasakiense*에 의한 multispecific red-tide인 반면 8월과 9월에는 *G. nagasakiense* 單一種에 의한 monospecific red-tide였다. 赤潮原因生物의 細胞數 變化는 7월에 *Prorocentrum* spp.가 0.3～12.5×10^5 cells/l, *G. nagasakiense*가 0.2～5.9×10^6 cells/l였으며, 8월과 9월에는 *G. nagasakiense*가 각각 1.1～4.7×10^6 cells/l, 0.2～15.1×10^6 cells/l를 나타내었다.

本 硏究에 있어서 *G. nagasakiense*에 의한 대규모 赤潮는 都市下水 및 工場廢水로 流入되는 각종 營養鹽類가 풍부하고, 높은 水溫과 심한 降雨量에 따라 예년보다 2～10

‰ 낮은 鹽分 등이 주 원인이었던 것으로 생각되었다.

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