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Influences of Oxygen-poor Water on Megabenthos Communities in Ise Bay, Central Japan

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Abstract

Oxygen-poor water ($O_2 \leqq 2$ppm) develops and prevails at the bottom of Ise Bay during summer to autumn every year mainly due to the progress of eutrophication. Two cruises were made to quantify influences of oxygen-poor water on megabenthos communities in the bay. First, in June 1992 when oxygen-poor water began to develop, and secondly, in October 1992 when the event was in a perishing phase. During June 1992, higher biomasses (wet weight/stn.) of megabenthos were found in the central and southern parts of the bay where oxygen-poor water had already developed. The reason why a strong impact of oxygen-poor water was not yet detected in June 1992 is probably due to its absence in May 1992. Contrastingly, in October 1992, megabenthos biomass found in the bay was extremely low, indicating mass mortality of megabenthos due to the presence of oxygen-poor water at the bottom for a long periods (4-5months).

Introduction

Development and prevalence of oxygen-poor water have frequently been observed in eutrophicated inlet and coastal waters all over the world during warm seasons (JORGENSEN, 1980; DETHLEFSEN and WESTERNHAGEN, 1982; WEIGELT and RUMOHR, 1986; PIHL *et al.*, 1991; ROSENBERG *et al.*, 1992). Also in Japanese waters (e.g., Tokyo, Ise, and Osaka Bays, and the Inland Sea of Seto), events of oxygen-poor water are well documented (Oceanographic Society of Japan, 1985).

Commercially important demersal fishes, shellfishes and so on are included in megabenthos. The events of oxygen-poor water have caused strong damage to fisheries of these organisms in eutrophicated inlet and coastal waters, so that this situation has promoted studies concerning the influences of the events on those fisheries (see, HIRANO, 1992). Shimizu and his colleagues have investigated the effects of the events on commercially important animals in Tokyo Bay, central Japan (TOKIMURA, 1985; SHIMIZU, 1988; OHTOMI *et al.*, 1988, 1989; IKESHIMA, 1995).

However, as far as we know, very little is known about influences of oxygen-poor water on megabenthos communities as a whole. Of previous work done on megabenthos, there are studies by SEKIGUCHI and his colleagues on megabenthos communities in Ise Bay (HOSSAIN *et al.*, 1996; AMAKAWA *et al.*, 1996). These works showed drastic changes in megabenthos biomass, spatial distribution of megabenthos density, and structure of megabenthos populations and communities in relation to the events of oxygen-poor water in the bay.

In the present study, we show another example of the oxygen-poor water event and its influence on megabenthos communities in Ise Bay in 1992 when the event was particularly more severe than in other years.

Materials and Methods

Study area

Ise Bay is a semi-closed bay located along the Pacific coast of central Japan and covers a surface area of 1,738km^2 with a mean depth of 19.5 m (Fig.

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1). The depth is slightly more than 30 m in the main basin and is separated from the Pacific Ocean through the Irago passage, which is 13km wide and 73 m deep. The Kiso River (KISO, NAGAWA, IBI), some of the biggest rivers in Japan, flow into the innermost part of the bay. The northern and central parts of the bay have silt-clay bottom, while the southern and southwestern parts have sand, rock and gravel bottoms (Fig. 2).

The water in the bay is rich in nutrients and highly turbid due to the freshwater discharge and sewage effluent from the cities on the western and northern coasts. With the recent progress of eutrophication in the bay, red tides are observed during summer every year followed by oxygen-poor water prevailing mainly and widely in the central part of the bay (Oceanographic Society of Japan, 1985).

Seasonal and spatial distributions of the dissoloved oxygen content in the bay from January to December 1992, according to the Prompt Report of Mie Prefectural Institute of Fisheries Technology, are shown in Fig. 3. Oxygen-poor water (i.e., 2 ppm or less) occurred and prevailed widely in the bottom layer (1 m above the bottom) of the central part of the bay mainly during June to October, 1992. The most severe condition was found to occur, however, during July to September when oxygen-poor water prevailed in the greater part of the bay.

Sampling and Data processing

Sampling was done in order to quantify the impact of oxygen-poor water on megabenthos communities in Ise Bay by a comparison between biomasses of megabenthos collected at the begining and ending of development of oxygen-poor water. Two cruises were made on board the T/V *Seisui Maru* of Mie University for collecting megabenthos in the bay. First, on the 16–19 June, 1992, when oxygen-poor water started to develop at bottoms of the bay, and second, on the 29-30 October, 1992, when oxygen-poor water was in a perishing phase.

In each cruise, 16–17 sampling stations were covered during the daytime. A small beam trawl was towed horizontally for 15 minutes on the bottom with a ship speed of 2 knots (1m/sec) at each sampling station, covering a bottom surface area of ca.1500m^2. This equipment has an iron frame fixed to the net, 4.4m in length, with a stretch mesh size of 27mm (Fig. 4). We define here the term 'megabenthos' as organisms collected using this equipment.

Catches, that were frozen immediately after sampling, were sorted out according to major taxonomic groups. The weights of specimens of each taxon were measured in the laboratory.

Results

Weights of total megabenthos and major taxa which were collected in June 1992, when oxygen-poor water began to develop at the bottom in the bay, are shown in Table 1 and Fig. 5. Total megabenthos weight collected from all sampling stations was 88kg. Three groups, viz., crustaceans, echinoderms and fishes were dominant among megabenthos amounting to 42.0kg, 16.4kg and 12.9kg of biomass, respectively. Of these three taxa, and also of the total megabenthos, five species were absolutely dominant in biomass; Stomatopoda: *Oratosquilla oratoria*, Brachyura: *Carcinoplax vestita* and *Charybdis bimaculata*, Asteroidea: *Luidia quinaria*, and Pisces: *Repomucenus valenciennei*.

Spatial distributions of biomasses (wet weight /stn.) of the total megabenthos and seven major taxa (mantis shrimps, shrimps, crabs, fishes, starfishes, sea-urchins and gastropods) are shown in Fig. 6. Higher biomasses of the total megabenthos were found in central and mouth parts of the bay, with the highest being 10kg/stn and 15kg/stn, respectively. Crustaceans and fishes contributed to form higher biomasses at sampling stations in the central parts where silt-clay bottom sediment prevails (Figs. 2, 6). On the contrary, echinoderms contributed to form higher biomasses at sampling stations in the areas where several types of bottom sediment are found (Figs. 2, 6). Interestingly, as

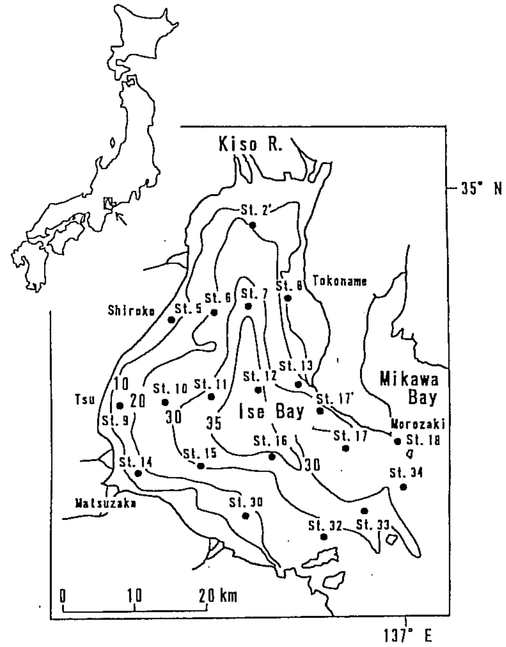

Fig. 1. Ise Bay and location of sampling stations. Solid circles and dotted lines indicate sampling stations and depth isopleths in meters, respectively.

indicated in Figs. 3 and 6, most of the sampling stations with higher biomasses of total megabenthos and also major taxa in June 1992 were located within the prevalent area of oxygen-poor water.

On the other hand, weights of the total megabenthos and major taxa which were collected in October 1992 when oxygen-poor water appeared to enter a perishing phase are both shown in Table 2 and Fig. 5. Total weight of megabenthos collected in the whole bay was remarkably low amounting to only 1,980g, decreasing drastically as compared to those (88kg) collected in June (Fig. 5). Biomass of megabenthos at each sampling station was also extremely low in October 1992 (Table 1). In fact, it was difficult to draw figures indicating spatial distribution of megabenthos biomass (wet weight/stn.) in the bay, because the megabenthos biomass occurring at each station was very negligible. However, species composition of megabenthos was almost the same as that found in June 1992.

Dead organisms, including crustaceans, echinoderms molluscans and fishes, were frequently

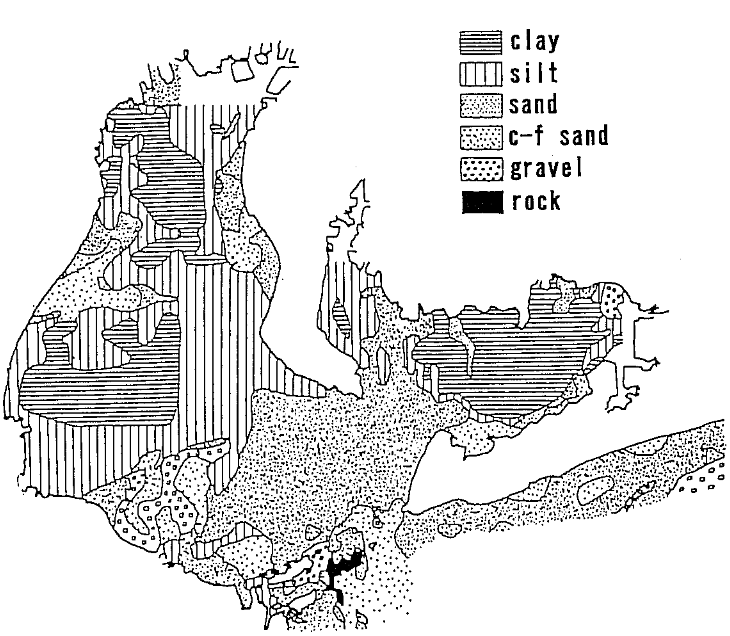

Fig. 2. Bottom sediment types in Ise Bay (from KITAMORI *et al.*, 1970 and partly revised). Sand indicates fine sand only and c-f sand indicates coarse to fine sands.

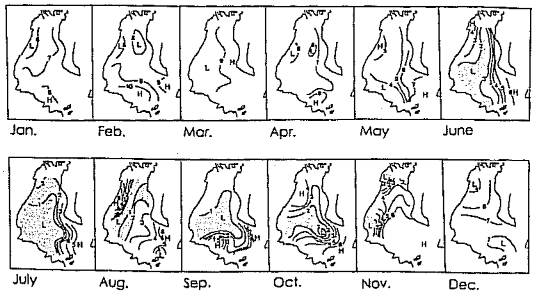

Fig. 3. Seasonal and spatial distributions of the dissolved oxygen content (ppm) in the water 1 m above the bottom in Ise Bay in 1992 (from the Prompt Report of Mie Prefectural Institute of Fisheries Technology).

Shaded areas indicate the areas with a dissolved oxygen content of 2 ppm or less.

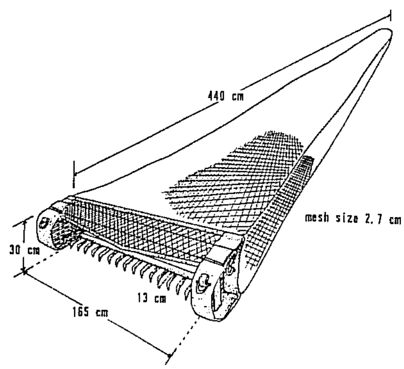

Fig. 4. Schematic illustration of the sampling gear for megabenthos

found in megabenthos samples collected at most sampling stations in October 1992 and also the peculiar smell of hydrogen sulphide was strongly detectable among megabenthos samples and sediments collected there. This indicates that hydrogen sulphide developed in most of the bottom sediment of the bay except the southern parts where oxygen-poor water was not found due probably to active exchange of the bay water with the open coastal water (Oceanographic Society of Japan, 1985).

Thus, according to the above-mentioned results, it is clear that development and prevalence of oxygen-poor water promote mass mortality of megabenthos, resulting in defaunation in the bay.

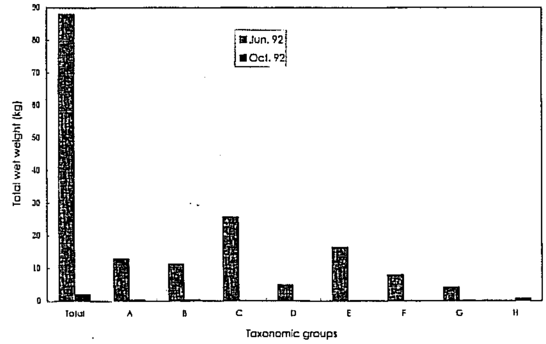

Fig. 5. Wet weights of major megabenthos taxa collected during the beginning and ending of oxygen-poor water events in Ise Bay in 1992.

The letter codes are as follows- A: fishes, B: mantis shrimps, C: crabs, D: shrimps, E: sea-stars, F: sea-urchins, G: gastropods, H: bivalves.

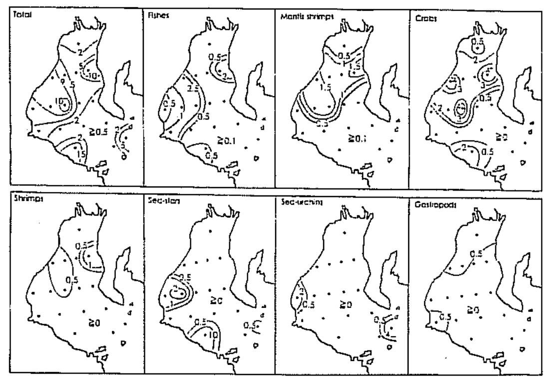

Fig. 6. Seasonal and spatial distributions of biomass (kg/stn.) of major megabenthos taxa in Ise Bay during June 1992 when oxygen-poor water just began to develop.

Discussion

Development of oxygen-poor water during warm periods has already been reported in Ise Bay (Oceanographic Society of Japan, 1985). Usually oxygen-poor water starts to develop in the central part of the bay from June and lasts until October over the wider parts of the bay. Oxygen-poor water is believed to occur in the bay with the progress of eutrophication. In Ise Bay, the prevalence of oxygen-poor water is detectable for a long period (usually 4–5 months), and results in defaunation of megabenthos in the bay every year (HOSSAIN *et al.*, 1996).

Missing weights of megabenthos can be an

Table 1. Biomass of megabenthos collected in Ise Bay during June 1992

Sampling stations	Biomass of major magabenthos taxs(kg)							Total (kg)
	A	B	C	D	E	F	G	
2'	0.2	0.2	0.5	0.1	0.0	0.0	0.7	1.9
5	1.3	1.7	4.3	0.9	0.3	0.4	0.5	9.3
6	0.5	1.4	2.4	0.5	?	0.0	0.8	5.5
7	0.0	1.2	2.2	0.3	0.0	0.0	0.3	4.6
8	2.3	1.7	4.1	1.1	0.1	0.0	0.4	10.7
9	0.2	0.3	0.9	0.1	1.0	2.6	0.1	5.2
10	0.8	1.8	2.7	0.4	2.7	0.0	0.1	9.3
11	2.3	1.6	4.6	0.9	0.0	0.0	0.3	10.6
12	0.2	0.1	0.1	0.1	0.2	0.0	0.1	0.7
13	0.4	0.1	0.2	0.1	0.1	0.1	0.1	1.0
14	2.7	0.2	0.0	0.0	0.0	0.0	0.5	3.9
15	0.4	0.4	0.8	0.1	0.0	0.0	0.1	1.6
16	0.1	0.2	0.2	0.1	0.0	0.0	0.1	0.5
17	0.4	0.1	0.1	0.1	0.3	0.0	0.0	0.8
30	0.8	0.1	2.4	0.0	11.5	0.3	0.0	16.2
33	0.2	0.1	0.1	0.1	0.1	0.4	0.0	1.1
34	0.1	0.1	0.1	0.1	0.1	4.2	0.1	5.1
Total (kg)	12.9	11.3	25.7	5.0	16.4	8.0	4.2	* 88.0

* : Total megabenthos biomass including major and minor groups, A : fishes, B : mantis shrimps, C : crabs, D : shrimps, E : sea-stars, F : sea-urchins and G : gastropods

Table 2. Biomass of megabenthos collected in Ise Bay during October 1992

Sampling stations	Biomass of major magabenthos taxa(g)							Total(g)
	A	B	C	D	F	G	H	
'2	13	32	10	0	0	12	59	130
5	0	57	3	0	0	11	56	171
6	0	0	0	0	0	0	80	80
7	11	0	0	0	0	0	61	72
8	23	4	8	4	0	58	74	169
9	0	3	0	0	0	0	0	3
10	4	13	0	0	0	0	208	245
11	9	20	0	0	0	0	79	108
12	21	72	2	0	0	0	41	136
13	27	49	39	2	0	22	71	223
14	103	27	10	2	0	0	70	212
15	71	18	0	14	0	0	0	103
16	21	56	0	0	0	0	0	80
17	10	0	1	13	71	3	0	121
30	61	19	0	30	0	0	0	110
33	13	0	0	1	1	0	0	15
Total(g)	387	370	73	66	72	106	799	* 1978

* : total megabenthos biomass including major and minor groups, A : fishes, B : mantis shrimps, C : crabs, D : shrimps, F : sea-urchins and G : gastropods and H : bivales

indicator to quantify the effect of oxygen-poor water in the bay. The missing weight can roughly be estimated as differences between weights of megabenthos collected at the beginning and ending of the oxygen-poor water event in the bay. Note that some stations that were not sampled at both the beginning and ending of the event have been excluded from the estimation of missing weight. In the present study, the missing weight amounted to nearly 81kg as compared to 1 kg in 1993 (HOSSAIN *et al.*, 1996) and 39 kg in 1994 (unpublished data). Hence, it is clear that the effect of oxygen-poor water on megabenthos communities in Ise Bay was most severe in 1992 (present study) as compared to that in 1993 and 1994. Of these three years, the influence of oxygen-poor water was least severe in 1993. Spatial and seasonal distributions of the dissolved oxygen content in 1993 also support this finding (HOSSAIN *et al.*, 1996). Due to a series of typhoons that passed through the bay in September 1993, a good mixing of water occurred which perhaps prevented the development of oxygen-poor water at the bottom. So, apparently, the greater the extent of oxygen-poor water, the more the missing weight and vice versa.

The seasonal and spatial distributions of megabenthos are remarkably influenced by oxygen-poor water in Ise Bay. Megabenthos biomass (wet weight/stn.) start decreasing from June and/or July as oxygen-poor water begins to develop and reach a minimum at the end of the event, and then megabenthos biomass start increasing from November when the oxygen condition on the bay bottom almost recovers (HOSSAIN *et al.*, 1996, unpublished data). As for present study, oxygen-poor water began to develop in a wider part of the bay from June and prevailed until November (Fig. 3). Meanwhile, the spatial distribution patterns of megabenthos biomasses vary year to year depending on the magnitude of developing oxygen-poor water in the bay. For example, in 1993, when oxygen-poor water did not seem to be too severe, higher biomasses of megabenthos were found in the central part of the bay at the beginning of the development of oxygen-poor water and at the marginal stations of the same areas at the end of the event (HOSSAIN *et al.* 1996). Contrastingly, in 1994, higher biomasses of megabenthos occurred in the central part of the bay before oxygen-poor water developed, while oxygen-poor water resulting in mass mortality developed and prevailed, and higher biomasses rather shifted in the southern part of the bay (unpublished data). In the present study, during the onset of oxygen-poor water event in the bay in June 1992, higher biomasses of megabenthos occurred at the central part of the bay where oxygen-poor water had already developed. A strong influence of oxygen-poor water on megabenthos in June 1992 was not yet detected because oxygen-poor water did not appear in May 1992 and then just began to develop in the bay in June 1992.

It is very difficult to exactly assess the ecological significance of oxygen-poor water that develops seasonally in neritic and coastal waters. In Ise Bay, the oxygen-poor water event lasts for quite a long period (about 4-5 months) every year, having a catastrophic effect on megabenthos communities. So, this particular phenomenon of developing oxygen-poor water could be rather alarming. Thus, we need further comprehensive studies to elucidate in some detail how the bay is ecologically stressed.

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References

AMAKAWA, T., M. HOSSAIN and H. SEKIGUCHI (1996) Distribution and population structure of megabenthos in Ise Bay, central Japan. Benthos Research (in press)

DETHLEFSEN, V. and H. V. WESTERNHAGEN (1982) Oxygen deficiency and effects on bottom fauna in the eastern German Bight 1982. Meeresforsch, 30, 43-53.

FUROTA, T. (1988) Effects of low-oxygen water on benthic and sessile animal communities in Tokyo Bay. Bull. Coast. Oceanogr, **25**: 104–113 (in Japanese).

HIRANO, T. (ed., 1992) Environmental Marine Sciences, Koseisha Koseikaku, Tokyo, 570 pp., (in Japanese).

HOSSAIN, M., T. AMAKAWA and H. SEKIGUCHI (1996) Density, biomass and community structure of megabenthos in Ise Bay, central Japan. Fisheries Science, 62, 350–360.

IKESHIMA, K. (1995) Life History of Hatatatenumeri Dragonet *Repomucenus valenciennei* in Tokyo Bay, Ph.D. Thesis, University of Tokyo, 199 pp. (in Japanese).

JORGENSEN, B. B (1980) Seasonal oxygen depletion in the bottom waters of a Danish Fjord and its effect on the benthic community. Oikos, **34**, 68–76.

KITAMORI, R., T. SUGINO and T. SAWADA (1970) Bottom quality and benthic animals in Ise Bay. In, Report on the survey for developing Fisheries in the Recess of Ise Bay, Ise Wan Fisheries Experimental Station (ed.), p. 5–40 (in Japanese).

Oceanographic Society of Japan (1985) Coastal Oceanography of Japanese Islands. Tokai University Press, Tokyo, 839pp. (in Japanese).

OHTOMI, J., M. SHIMIZU and J. A. MARTINEZ VERGARA (1988) Spawning season of the Japanese mantis shrimp *Oratosquilla oratoria* in Tokyo Bay. Nippon Suisan Gakkaishi, **54**, 1929–1933 (in Japanese).

OHTOMI, J., J. S. PARK and M. SHIMIZU (1989). The distribution of the Japanese mantis shrimp *Oratosquilla oratoria* and its relationship to fishing grounds in Tokyo Bay. Nippon Suisan Gakkaishi, **55**, 1529–1538 (in Japanese).

PIHL, L., S. P. BADEN and R. J. DIAZ (1991) Effects of periodic hypoxia on distribution of demersal fish and crustaceans. Mar. Biol., 108, 349–360.

ROSENBERG, R., L. OVELOO and P. MOLLER (1992) Hypoxia, salinity and temperature as structuring factors for marine communities in a eutrophic area. Neth. J. Sea Res., **30**, 121–129.

SHIMIZU, M. (1988) Distribution of benthic fishes and shell fishes in Tokyo Bay. Bull. Coast. Oceanogr, **25**, 96–103 (in Japanese).

TOKIMURA, M. (1985) On the Structure of the Distribution of Demersal Fish and Shellfish in the Inner Part of Tokyo Bay. Ph.D. Thesis, University of Tokyo, 156 pp. (in Japanese).

WEIGELT, M. and H. RUMOHR (1986) Effects of wide-range oxygen depletion on benthic fauna and demersal fish in Kiel Bay 1981–1983. Meeresforsch, **31**, 124–136.

伊勢湾のメガベントスへの貧酸素水の影響

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富栄養化の進行に伴って，毎年夏から秋にかけて伊勢湾の底層に 2 ppm以下の貧酸素域が発達する。伊勢湾のメガベントスへの貧酸素水の影響を把握するために，２つの調査航海が1992年の６月と10月におこなわれた。貧酸素水の発達初期の６月には，メガベントスの高密度域は湾の中央域から北部域にあり，そこでは既に貧酸素水が発達していた。恐らくは，５月には貧酸素水が未だ発達せず，６月は貧酸素水の発達初期であったので，メガベントスへの影響が未だ顕著に現われていなかったと推察される。一方，貧酸素水の消滅期である10月には，メガベントスの生物量は著しく小さかったが，これは10月以前の貧酸素水の発達とその継続による大量死亡に起因する。

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