Bull. Fac. Fish., Mie Univ.
No. 11 : 57−67
October 1, 1984

Studies on Microbial Population in Coastal Waters− I Distribution of Nitrogen-cycle Bacteria in the Kumano Nada and its Adjacent Areas*

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The occurrence and distribution of nitrogen-cycle bacteria in the Kumano Nada and its adjacent areas were studied during 1981−1983.

Heterotrophic bacteria in the water usually occurred at the level of 10^0-10^4/ml. The distribution of heterotrophic bacteria was uneven horizontally as well as vertically. The number of nitrate-reducing bacteria was in the order of $10^{-1}-10^3$ cells/ml, while denitrifying bacteria were in the range from 10^{-1} to 10^2 cells/ml or sometimes lower than the value. The occurrence of nitrogen-fixing bacteria and nitrifying bacteria in the surface water was also very few ranging from 10^0 to 10^2 cells/l.

Key words: nitrogen-cycle bacteria, nitrate-reducing bacteria, denitrifying bacteria, nitrifying bacteria, nitrogen-fixing bacteria, microbial population, Kumano Nada

Organic substances or nutrient salts are brought with terrestrial runoff such as river water into neritic waters. Therefore, coastal waters are usually richer in biomass than the open sea. In general, productivity as well as biomass of community increases from the ocean to the shore.

Nitrogen is one of the most important bioelements, and its content is quite small in aquatic environments. Each of the reactions in the nitrogen cycle is mainly carried out by the action of microorganisms. In coastal waters, bacteria are thought to play an important role in the cycle of matter. The form and concentration of nitrogenous compounds sometimes control the productivity of community in aquatic environments.

The present paper deals with the occurrence and distribution of nitrogen-cycle bacteria in the Kumano Nada and its adjacent areas.

Methods

Collection of water and bottom sediment samples

The seawater and sediment samples from the Kumano Nada and its adjacent areas were collected during the cruises of 81-R-2, 81-R-6, 81-R-10, 82-R-2, 82-R-6, 82-R-9,

* Contribution from training ship Seisui-Maru, Mie University

83-R-2 and 83-R-5, respectively by the Seisui-Maru of Mie University. Fig. 1 shows the location of sampling stations.

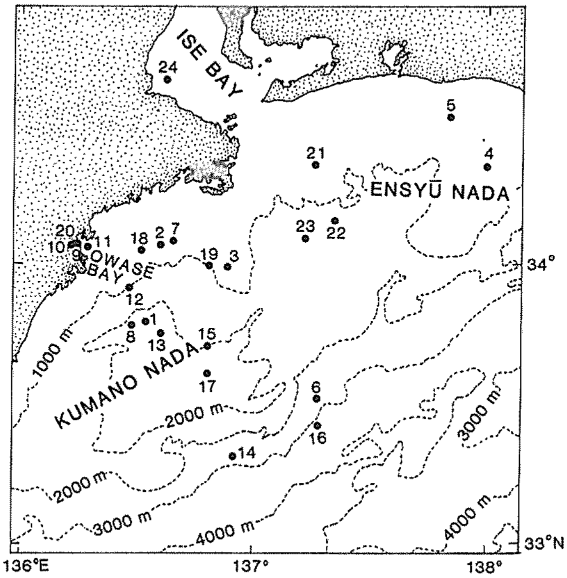

Fig. 1. Location of sampling stations in the Kumano Nada and its adjacent areas.

Enumeration of bacterial number

Viable counts of aerobic heterotrophic bacteria were determined by the spread plate method and the M. P. N. method. The composition of medium for culturing the heterotrophic bacteria is given as Medium I and Medium II of Table 1. All plates and M.

Table 1. Composition of media used in this study

Medium I (for heterotrophs, nitrate-reducers and denitrifiers)		Medium II (for heterotrophs)	
Polypepton (Daigo)	5.0 g	Polypepton (Daigo)	10.0 g
Yeast extract (Nakarai)	2.0 g	Yeast extract (Nakarai)	5.0 g
KNO_3	1.0 g	Starch	2.0 g
Artificial seawater	1,000 ml	*Micrococcus luteus* cells	1.0 g
		Agar	15.0 g
		Tap water	100 ml
		Aged seawater	900 ml
Medium III (for nitrifiers)		Medium IV (for nitrogen fixers)	
$(NH_4)_2SO_4$	30 mg	Sucrose	20.0 g
KH_2PO_4	100 mg	Glucose	10.0 g
EDTA-Fe	6 mg	KH_2PO_4	0.2 g
$CaCO_3$	little	$Na_2MoO_4 \cdot 2H_2O$	0.01 g
Artificial seawater	1,000 ml	$FeSO_4 \cdot 7H_2O$	0.001 g
		$MnSO_4$	0.001 g
		Artificial seawater	1,000 ml

Artificial seawater; NaCl 30.0 g, KCl 0.7 g, $MgCl_2 \cdot 6H_2O$ 10.8 g, $MgSO_4 \cdot 7H_2O$ 5.4 g, $CaCl_2 \cdot 2H_2O$ 1.0 g, Distilled water 1,000 ml.

P. N. tubes inoculated were incubated at 25°C for 3−14 days.

Nitrate-reducing bacteria, denitrifying bacteria, nitrifying bacteria and nitrogen-fixing bacteria were counted by the M. P. N. method. The composition of each medium for culturing these nitrogen-cycle bacteria is shown in Table 1. Cultivation was done at 25 °C for 2 weeks for nitrate-reducing bacteria and denitrifying bacteria, and for at least 2 months for nitrifying bacteria and nitrogen-fixing bacteria.

Results and Discussion

Distribution of heterotrophic bacteria in the water

Table 2. Distribution of heterotrophic bacteria in the water of the Kumano Nada and its adjacent areas

Depth (m)	Temp. (°C)	Salinity (‰)	Heterotrophs (cfu/ml)	Depth (m)	Temp. (°C)	Salinity (‰)	Heterotrophs (cfu/ml)
Station 1 (33°47.2'N, 136°32.1'E) May 6, 1981 ; station depth 2,050 m.				Station 2 (34°03.9'N, 136°35.8'E) May 8, 1981 ; station depth 497 m.			
0	18.9	——	3.5×10^2	0	20.44	——	4.2×10^2
200	11.664	34.431	2.3×10^2	50	17.697	34.652	4.5×10^2
400	6.954	34.230	4.0×10^2	100	15.649	34.633	6.4×10^2
600	5.348	34.293	4.4×10^2	150	13.717	34.544	4.4×10^2
800	4.197	34.356	5.0×10	200	12.198	34.469	1.3×10^2
1,000	3.319	34.440	5.0×10	250	10.884	34.406	1.4×10^2
1,200	2.934	34.480	2.3×10^2	300	8.879	34.323	8.7×10^2
1,400	2.555	34.524	1.6×10^2	350	7.713	34.278	3.7×10^2
1,600	2.332	34.552	1.6×10^2	400	7.103	34.283	2.7×10^2
1,800	2.202	34.572	7.0×10	450	6.375	34.284	1.2×10^2
2,000	2.006	34.601	1.0×10^2	470	5.665	34.299	3.7×10^2
Station 3 (33°59.5'N, 136°52.9'E) May 9, 1981 ; station depth 1,010 m.				Station 4 (34°20.5'N, 137°59.6'E) Sept. 17, 1981 ; station depth 579 m.			
0	19.7	——	3.4×10^2	0	23.5	——	1.2×10^3
100	15.111	34.615	4.8×10^2	50	20.844	34.434	1.3×10^2
200	11.824	34.468	3.8×10^2	100	16.056	34.595	1.6×10^2
300	9.702	34.350	2.4×10^2	150	13.455	34.521	1.1×10^2
400	7.759	34.286	1.5×10^2	200	12.538	34.475	8.0×10
500	6.404	34.270	5.0×10	250	11.651	34.438	1.8×10^2
800	4.208	34.363	4.5×10^2	300	9.995	34.360	8.0×10
1,000	3.237	34.449	5.0×10	350	9.248	34.329	7.0×10
				400	7.628	34.272	1.0×10
				450	6.629	34.272	7.0×10
				550	5.270	34.305	5.0×10
				575	5.159	34.242	0
Station 5 (34°30.9'N, 137°49.7'E) Sept. 18, 1981 ; station depth 468 m.				Station 6 (33°31.3'N, 137°16.3'E) Nov. 6, 1981 ; station depth 3,150 m.			
0	23.4	——	1.1×10^3	0	22.5	——	1.1×10^3
4	23.438	34.187	1.9×10^2	100	21.887	34.592	1.0×10^2
50	23.129	34.246	1.4×10^3	200	12.917	34.495	3.9×10^2

100	17.297	34.568	1.7×10^{2}
125	16.273	34.584	4.6×10^{2}
150	14.420	34.556	2.9×10^{2}
200	12.504	34.478	2.0×10
250	10.339	34.378	2.0×10
300	9.443	34.336	2.7×10^{2}
350	7.610	34.278	1.7×10^{2}
400	6.558	34.273	1.0×10^{2}
450	6.139	34.283	1.3×10^{2}
454	6.077	34.285	3.7×10^{2}

300	9.832	34.327	7.8×10^{2}
400	7.091	34.276	1.2×10^{3}
500	5.035	34.265	3.7×10^{2}
600	4.386	34.328	1.6×10^{2}
800	3.556	34.415	2.8×10^{2}
1,000	3.119	34.458	1.3×10^{2}
1,500	2.315	34.553	9.0×10^{2}
2,000	1.979	34.601	7.0×10
2,500	1.684	34.643	1.2×10^{2}

Station 7 (34°04.7′N, 136°39.1′E)
Nov. 7, 1981; station depth 564 m.

0	22.3	——	4.6×10^{2}
25	22.323	34.290	1.0×10
50	22.362	34.379	2.4×10^{2}
100	19.347	34.830	9.0×10
150	16.781	34.743	1.1×10^{3}
200	15.238	34.627	1.7×10^{2}
250	13.922	34.543	1.8×10^{2}
300	12.529	34.455	3.5×10^{2}
350	10.245	34.351	3.9×10^{2}
400	8.808	34.240	2.9×10^{2}
500	7.060	34.199	1.5×10^{2}
550	6.161	34.211	1.9×10^{2}

Station 8 (33°46.3′N, 136°28.9′E)
Apr. 25, 1982; station depth 2,050 m.

0	19.4	——	2.2×10^{3}
100	16.240	34.633	8.0×10
200	12.492	34.478	2.5×10^{3}
400	7.106	34.225	1.3×10^{3}
600	5.166	34.270	2.0×10^{2}
800	4.474	34.312	9.5×10^{2}
1,000	3.551	34.398	3.1×10^{2}
1,200	3.034	34.456	1.2×10^{3}
1,400	2.662	34.503	4.6×10^{3}
1,600	2.385	34.539	1.2×10^{3}
1,800	2.196	34.564	1.2×10^{2}
2,000	1.986	34.594	2.1×10^{2}

Station 9 (34°04.1′N, 136°13.1′E)
Apr. 24, 1982; Owase Bay.

0	18.2	——	2.1×10^{3}

Station 10 (34°04.4′N, 136°14.3′E)
Apr. 24, 1982; Owase Bay.

0	16.5	——	1.6×10^{3}

Station 11 (34°03.9′N, 136°16.7′E)
Apr. 24, 1982; Owase Bay.

0	16.1	——	$<1.0\times10^{2}$

Station 12 (33°54.6′N, 136°28.0′E)
Apr. 24, 1982

0	18.3	——	$<1.0\times10$

Station 14 (33°18.3′N, 136°55.3′E)
May 22, 1982; station depth 2,850 m.

0	20.0	——	6.0×10^{2}

Station 20 (34°04.3′N, 136°13.4′E) Owase Bay.
Apr. 25, 1983; station depth 25 m.

0	——	——	6.4×10^{4}

Station 13 (33°44.8′N, 136°36.3′E)
May 21, 1982; station depth 2,030 m.

0	20.4	——	2.6×10^{2}
100	15.636	34.645	1.4×10^{2}
200	11.927	34.435	1.1×10^{4}
400	6.670	34.269	7.1×10^{2}
600	4.405	34.305	1.2×10^{3}
800	3.712	34.387	1.2×10^{3}
1,000	3.295	34.432	3.8×10^{2}
1,200	2.893	34.479	1.2×10^{2}
1,400	2.514	34.524	3.0×10^{2}
1,600	2.313	34.551	8.2×10^{2}
1,800	2.070	34.585	1.1×10^{3}
2,000	1.941	34.602	7.5×10^{2}

Station 15 (33°42.1′N, 136°48.3′E)
Sept. 9, 1982; station depth 2,030 m.

0	25.7	——	9.0×10
50			3.0×10^{2}
100			1.5×10^{2}
200			1.6×10^{3}
400			$<1.0\times10$
600			1.0×10
800			9.1×10^{2}
1,000			8.1×10^{2}
1,200			3.1×10^{3}
1,400			2.1×10^{3}
1,600			3.0×10
1,800			1.0×10
2,000			1.0×10

Station 16 (33°25.3′ N, 137°17.2′ E)
Apr. 24, 1983; station depth 3,170m.

0	17.6	——	2.0×10^2
100	14.267	34.505	3.0×10
200	10.053	34.285	1.0×10
400	6.046	34.183	8.5×10
600	4.289	34.257	1.5×10
800	3.516	34.331	8.5×10
1,000	3.120	34.376	8.5×10
1,200	2.836	34.407	2.5×10
1,600	2.355	34.468	1.5×10
1,800	2.150	34.496	$<1.0\times10$
2,000	1.994	34.518	4.0×10
3,000	1.557	34.579	7.0×10

Station 17 (33°36.3′ N, 136°48.1′ E)
Apr. 24, 1983; station depth 2,060 m.

0	18.1	——	2.8×10^2
50	16.167	34.549	1.0×10^2
100	14.205	34.509	2.5×10
200	9.825	34.286	5.5×10
400	6.156	34.185	1.0×10^2
600	4.576	34.232	3.5×10
800	3.659	34.315	1.0×10
1,000	3.159	34.372	8.5×10
1,200	2.832	34.410	5.5×10
1,400	2.557	34.445	1.0×10
1,600	2.333	34.474	$<1.0\times10$
1,800	2.214	34.492	5.0×10
2,000	2.061	34.513	1.0×10

Station 18 (34°02.4′ N, 136°31.4′ E)
Apr. 25, 1983; station depth 549 m.

0	17.5	——	6.7×10^2
25	16.405	34.356	7.0×10
50	15.850	34.498	1.0×10
100	13.951	34.486	1.0×10
150	12.841	34.415	2.0×10
200	10.238	34.277	1.0×10
250	8.816	34.222	$<1.0\times10$
300	7.809	34.198	2.0×10
350	7.261	34.189	8.0×10
400	6.538	34.178	4.0×10
450	5.960	34.184	5.0×10
500	5.389	34.194	7.0×10
540	5.126	34.203	5.0×10

Station 21 (34°21.0′ N, 137°15.0′ E)
May 22, 1983; station depth 155 m.

0	20.6	——	1.0×10^2
10	20.263	34.252	1.7×10^2
30	19.241	34.403	2.3×10^2
40	19.229	34.403	2.4×10^2
50	18.899	34.420	1.4×10^2
60	18.486	34.434	3.1×10^2
70	16.693	34.527	1.2×10^2
80	16.203	34.542	2.2×10^2
90	15.961	34.548	1.6×10^2
100	15.649	34.547	2.1×10^2
145	14.113	34.331	1.1×10^2

Station 19 (33°59.9′ N, 136°48.1′ E)
Apr. 25, 1983; station depth 1,045 m.

0	18.6	——	2.4×10^3
100	14.785	34.553	7.0×10
200	10.961	34.324	1.0×10
400	6.357	34.185	2.0×10
600	4.633	34.236	1.0×10
800	3.886	34.295	$<1.0\times10$
1,000	3.482	34.338	$<1.0\times10$

Station 24 (34°38.2′ N, 136°37.1′ E) Ise Bay.
May 23, 1983; station depth 22.0 m.

0	20.9	——	5.2×10^3

Station 22 (34°08.9′ N, 137°20.7′ E)
May 22, 1983; station depth 1,285 m.

0	21.1	——	6.6×10^2
100	15.520	34.500	1.6×10^2
200	11.622	34.357	1.5×10
300	9.978	34.271	4.0×10
400	7.923	34.192	5.5×10
500	6.512	34.178	3.0×10
600	5.311	34.197	$<1.0\times10$
700	4.668	34.230	$<1.0\times10$

Station 23 (34°05.4′ N, 137°13.2′ E)
May 23, 1983; station depth 1,770 m.

0	20.9	——	5.5×10
100	15.433	34.518	1.2×10^2
200	11.136	34.323	3.5×10
300	9.698	34.270	5.0
400	7.586	34.183	1.5×10
500	6.126	34.175	5.0×10
600	5.198	34.198	2.5×10
800	4.110	34.273	$<1.0\times10$

800	4.279	34.260	5.0×10	1,000	3.449	34.339	$<1.0\times10$
900	3.838	34.297	$<1.0\times10$	1,200	3.015	34.390	1.0×10
1,000	3.544	34.327	1.0×10	1,400	2.661	34.432	$<1.0\times10$
1,100	3.301	34.354	$<1.0\times10$	1,600	2.376	34.469	1.0×10
1,250	2.966	34.394	3.0×10	1,736	2.240	34.483	$<1.0\times10^2$

Table 2 shows the number of heterotrophic bacteria counted by the spread plate method. Heterotrophic bacteria in the water usually occurred at the level of 10^0-10^3 cfu/ml, except for 6.4×10^4 cfu/ml in Owase Bay (station 20). Although the maximum bacterial number was observed in the surface water at each station, the vertical distribution of heterotrophic bacteria had no distinct tendency.

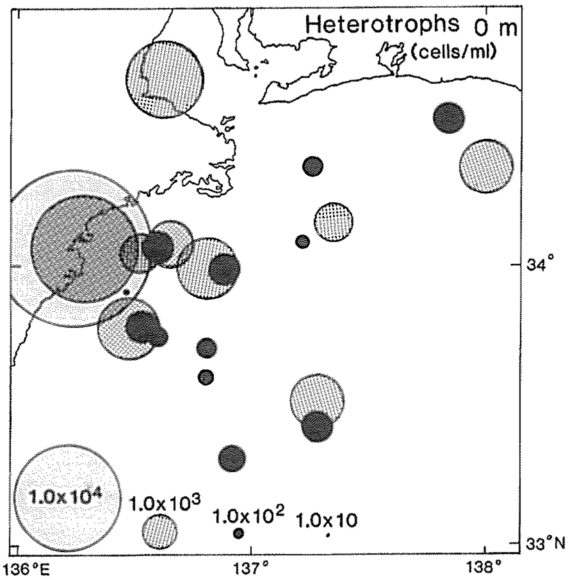

Fig. 2. Distribution of heterotrophic bacteria in the surface water of the Kumano Nada and its adjacent areas.

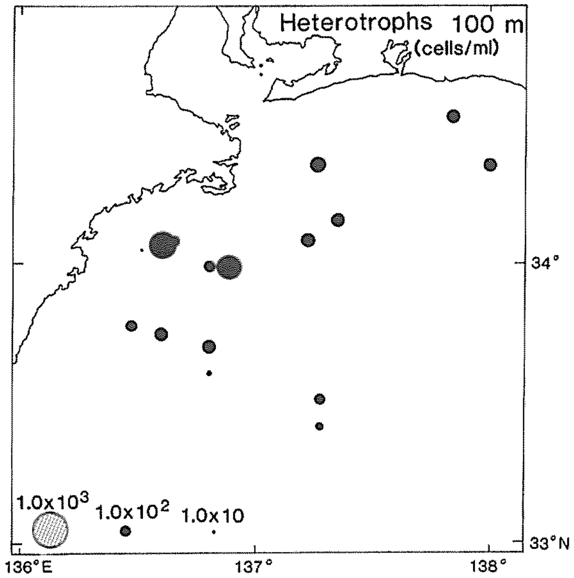

Fig. 3. Distribution of heterotrophic bacteria in the water at the depth of 100 m.

Figs. 2–5 show the distribution of heterotrophic bacteria enumerated by the M. P. N. method. The results in Fig. 2 indicated that heterotrophic bacteria in the surface water were generally in the order of 10^1-10^3 cells/ml. High count (2.4×10^4 cells/ml) was detected in Owase Bay (station 20). As shown in Figs. 3, 4 and 5, the bacterial counts in the water were at most 10^2 cells/ml at 100 m layer and 10^1-10^3 cells/ml at 400 m layer, while the numder ranged from 10^0 to 10^4 cells/ml at 200 m layer. The distribution of heterotrophic bacteria was uneven horizontally as well as vertically.

The heterotrophic bacteria in the water were only 10^0-10^2 cells/ml in offshore regions such as Suruga Bay and Sagami Bay, while the number was in the range from

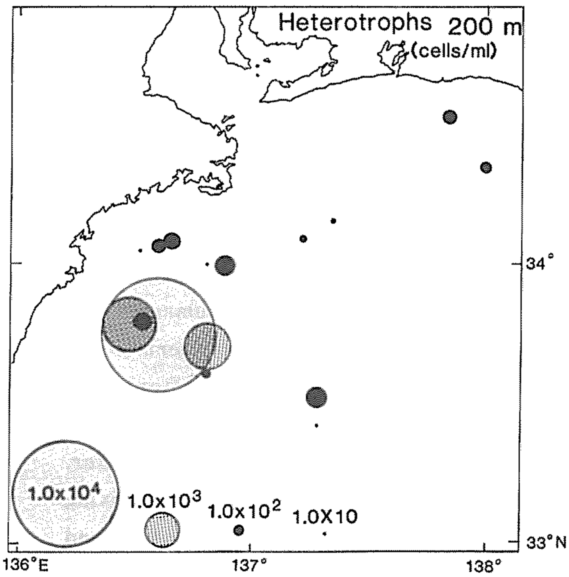

Fig. 4. Distribution of heterotrophic bacteria in the water at the depth of 200 m.

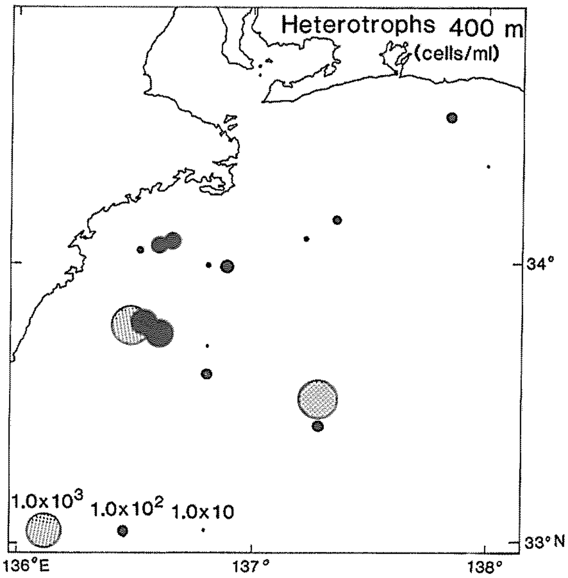

Fig. 5. Distribution of heterotrophic bacteria in the water at the depth of 400 m.

10^2 to 10^4 cells/ml in coastal regions such as Kumihama Bay, Maizuru Bay, Mikawa Bay, Fukuyama Bay and the Hibiki Nada (KAWAI and SUGAHARA 1971a, 1971b, MURAKAMI and FUJISAWA 1978, FUJISAWA *et al.* 1978, KAWAKAMI *et al.* 1981).

Distribution of nitrogen-cycle bacteria in the Kumano Nada and its adjacent areas

Table 3. Distribution of nitrogen-cycle bacteria in the surface water and bottom sediment of the Kumano Nada and its adjacent areas

Date	Station		Heterotrophs		Nitrate reducers	Denitrifiers	N_2 fixers	Nitrifiers
			cfu/ml, g	cells/ml, g	cells/ml, g	cells/ml, g	cells/l, g	cells/l, g
1983.4.25	St. 20 (Owase Bay)	Weter	6.4×10^4	2.4×10^4 (100.0%)	1.4×10^3 (5.8%)	2.0×10^2 (0.83%)	200 (0.0009%)	330 (0.0014%)
1983.5.22	St. 21	Water	1.0×10^2	3.3×10^2 (100.0%)	1.3×10 (3.9%)	2.0 (0.61%)	170 (0.0515%)	4.5 (0.0014%)
1983.5.22	St. 22	Water	6.6×10^2	1.3×10^3 (100.0%)	1.3×10^2 (10.0%)	4.9×10 (3.8 %)	81 (0.0062%)	240 (0.0185%)
1983.5.23	St. 23	Water	5.5×10	1.3×10^2 (100.0%)	3.3 (2.5%)	<0.2 (<0.15%)	27 (0.0208%)	7.8 (0.0060%)
1983.5.23	St. 24 (Ise Bay)	Water	5.3×10^3	4.9×10^3 (100.0%)	1.2×10^2 (2.4%)	$<2.0\times10$ (<0.41%)	23 (0.0005%)	<20 (<0.0004%)
	Average			100.0%	4.9%	1.7%	0.016%	0.007%
1983.4.24	St. 16(3270m) (Kumano Nada)	Sediment	2.1×10^4	2.4×10^4 (100.0%)	1.5×10^3 (6.3%)	1.2×10^3 (5.0 %)	2.1×10 (0.09%)	1.7×10 (0.07%)

Values in parentheses show the ratio (%) of the number of each of nitrogen-cycle bacteria to that of heterotrophs.

As shown in Table 3, in the surface water of bays such as Owase Bay and Ise Bay, aerobic heterotrophic bacteria were abundant, i.e. 10^3-10^4 cells/ml as compared with those of offshore regions (stations 21, 22 and 23), i.e. 10^1-10^3 cells/ml. Nitrate-reducing bacteria in the surface water occurred at the level of 10^0-10^3 cells/ml, whereas denitrifying bacteria were in the range from 10^{-1} to 10^2 cells/ml or sometimes lower than the value. However, nitrogen-fixing bacteria and nitrifying bacteria in the surface water were very few ranging from 10^0 to 10^2 cells/l.

On the other hand, the number of aerobic heterotrophic bacteria in the bottom sediment (0-5 cm layer) collected at station 16 (3,270 m in depth) of the Kumano Nada was in the order of 10^4 cells per 1 g of wet sediment. Nitrogen-fixing bacteria and nitrifying bacteria were in the order of 10 cells/g, while nitrate-reducing bacteria and denitrifying bacteria occurred at the level of 10^3 cells/g. Nitrogen-fixing bacteria and nitrifying bacteria occurred more abundantly in the bottom sediment than in the water.

According to KAWAI and SUGAHARA (1971a, 1971b), the population of nitrogen-fixing bacteria in the water was 10^1-10^2 cells/ml in enclosed bays such as Maizuru Bay and Kumihama Bay in Kyoto Prefecture, while the number was quite small in offshore waters in Suruga Bay and Sagami Bay, i.e. 0 – 800 cells/l. In the open sea such as the East China Sea, the Japan Sea and the Mid-Pacific Ocean, nitrogen-fixing bacteria were at most 400 cells/l. However, nitrogen-fixing bacteria occurred abundantly in the bottom sediments, namely 1 – 10 cells per 1 g of wet mud in offshore regions and open sea such as Suruga Bay, Sagami Bay and the East China Sea.

KIMATA *et al.* (1963) reported that nitrifying bacteria in the seawater of Maizuru Bay were hardly found, i.e. ca. 1 cell/ml or less and the bacterial counts in the bottom sediments were very large i.e. 10^2-10^5 cells/g. YOSHIDA and KIMATA (1967) also demonstrated that the counts of nitrifying bacteria were very low, i.e. 10^0-10^2 cells/l and ca. 10^1 cells/g or less in Wakasa Bay and its offshore region.

The results in Table 3 were comparable to the data of KAWAI and SUGAHARA (1971a, 1971b), KIMATA *et al.* (1963) and YOSHIDA and KIMATA (1967).

Vertical distribution of nitrate-reducing bacteria and denitrifying bacteria in the water column

Table 4. Vertical distribution of nitrate-reducing bacteria and denitrifying bacteria in the water of the Kumano Nada and its adjacent areas

Station	Depth (m)	Heterotrophs (cells/ml)	Nitrate reducers (cells/ml)	Denitrifiers (cells/ml)
Station 6 (Nov. 6, 1981)	0	2.2×10^3	4.9×10 (2.2 %)	22 (1.0 %)
	100	1.7×10	1.3×10 (76.5 %)	1.3 (7.6 %)
	200	$>1.6\times10^2$ (3.9×10^2)*	2.8×10 (7.2 %)	2.6 (0.67%)
	300	$>1.6\times10^2$ (7.8×10^2)*	5.4×10 (6.9 %)	0.93 (0.12%)
	400	$>1.6\times10^2$ (1.2×10^3)*	$>1.6\times10^2$	2.8 (0.23%)
	500	$>1.6\times10^2$ (3.7×10^2)*	9.2×10 (24.9 %)	4.7 (1.3 %)

	800	>1.6×10^2 (2.8×10^2)*	1.6×10^2 (57.1 %)	22 (7.9 %)
	1,000	1.6×10^2	5.4×10 (33.8 %)	5.6 (3.5 %)
	1,500	>1.6×10^2 (9.0×10^2)*	9.2×10 (10.2 %)	3.4 (0.38%)
	2,000	>1.6×10^2	1.1×10	11
Station 8 (Apr. 25, 1982)	0	3.5×10^3	3.3×10^2 (9.4 %)	330 (9.4 %)
	100	1.4×10^2	6.4×10 (45.7 %)	<0.2
	200	>1.6×10^3 (2.5×10^3)*	3.3×10 (1.3 %)	0.2 (0.01%)
	600	3.5×10^2	4.9×10 (14.0 %)	4.8 (1.4 %)
	1,000	>1.6×10^3	7.0×10	0.4−4.0
	1,600	>1.6×10^3	4.6×10	0.4
	2,000	3.5×10^2	3.5×10^2 (100.0 %)	2.0 (0.57%)
Station 13 (May 21, 1982)	0	3.3×10^2	4.9×10 (14.8 %)	22 (6.7 %)
	100	4.0×10	1.3×10 (32.5 %)	0.4 (1.0 %)
	200	1.8×10^4	6.4×10 (0.36%)	24 (0.13%)
	400	1.3×10^3	1.7×10 (1.3 %)	1.1 (0.08%)
	600	7.9×10^2	1.4×10 (1.8 %)	0.78 (0.10%)
	800	2.2×10^3	1.1×10^3 (50.0 %)	47 (2.1 %)
	1,000	3.5×10^3	4.0 (0.11%)	2.4 (0.07%)
	1,200	7.0×10^2	7.9×10 (11.3 %)	33 (4.7 %)
	1,400	3.3×10^2	2.1×10 (6.4 %)	1.1 (0.33%)
	1,600	9.2×10^3	2.4×10 (0.26%)	13 (0.14%)
	1,800	2.4×10^3	1.3×10^2 (5.4 %)	130 (5.4 %)
	2,000	1.7×10^3	4.9×10 (2.9 %)	33 (1.9 %)
Station 15 (Sept. 9, 1982)	0	3.3×10^2	2.6×10 (7.9 %)	1.8 (0.55%)
	50	1.1×10^2	4.5 (4.1 %)	<2.0
	100	2.2×10^2	3.3×10 (15.0 %)	0.18 (0.08%)
	200	1.8×10^3	7.9×10 (4.4 %)	49 (2.7 %)
	400	3.3	3.3 (100.0 %)	<0.2
	600	1.3×10	2.3 (17.7 %)	<0.2
	800	2.4×10^3	3.1×10 (1.3 %)	2.2 (0.09%)
	1,000	9.5×10^2	2.2×10 (2.3 %)	<0.2
	1,200	1.6×10^4	4.9×10^2 (3.1 %)	2.1 (0.01%)
	1,400	3.5×10^3	4.9×10^2 (14.0 %)	490 (14.0 %)
	1,600	1.3×10^2	2.2 (1.7 %)	0.18 (0.14%)
	1,800	1.7	1.7 (100.0 %)	<0.2
	2,000	7.9	0.45 (5.7 %)	<0.2
Station 16 (Apr. 24, 1983)	0	7.9×10^2	1.4×10^2 (17.7 %)	2.0 (0.25%)
	100	3.3×10	4.9 (14.8 %)	<0.2
	200	7.9×10	1.1×10 (13.9 %)	<0.2
	400	3.3×10	1.1×10 (33.3 %)	0.45 (1.4 %)
	600	7.9	2.7 (34.2 %)	0.2 (2.5 %)
	800	2.8×10	1.1×10 (39.3 %)	<0.2
	1,000	1.1×10	1.1×10 (100.0 %)	<0.2
	1,200	1.7×10	1.1×10 (64.7 %)	<0.2
	1,600	4.9	4.9 (100.0 %)	<0.2
	1,800	1.7	1.7 (100.0 %)	<0.2
	2,000	5.6	1.3 (23.2 %)	<0.2
	3,000	1.1×10^2	2.6×10 (23.6 %)	<0.2

Station 17 (Apr. 24, 1983)	0	2.2×10^2	7.9×10 (35.9 %)	4.5 (2.0 %)
	1,000	7.9×10	2.2×10 (27.8 %)	0.45 (0.57%)
	2,000	4.6	3.3 (71.7 %)	<0.2
Station 23 (May 23, 1983)	0	1.3×10^2	3.3 (2.5 %)	<0.2
	100	7.9×10	1.7×10 (21.5 %)	<0.2
	200	1.3×10^2	4.9 (3.8 %)	<0.2
	300	3.3×10	7.9 (23.9 %)	<0.2
	400	1.7×10	3.3 (19.4 %)	<0.2
	500	9.2×10	4.9 (5.3 %)	<0.2
	600	4.9×10	1.3×10 (26.5 %)	2.3 (4.7 %)
	800	2.3×10	4.9 (21.3 %)	<0.2
	1,000	3.1	0.78 (25.2 %)	<0.2
	1,200	1.3×10	1.4 (10.8 %)	<0.2
	1,400	4.9	0.78 (15.9 %)	<0.2
	1,600	1.1×10	4.6 (41.8 %)	<0.2
	1,750	1.3×10^2	2.0×10 (15.4 %)	<20

* Heterotrophs ; values in parentheses show bacterial number counted by the spread plate method. Nirate reducers and denitrifiers ; values in parentheses show the ratio (%) of the number of nitrate reducers or denitrifiers to that of heterotrophs.

The results in Table 4 indicated that the population of nitrate-reducing bacteria ranged from 10^{-1} to 10^3 cells/ml, while the occurrence of denitrifying bacteria was very poor, i. e. $10^{-1}-10^2$ cells/ml or less. The ratio of the number of nitrate-reducing bacteria or denitrifying bacteria to that of heterotrophic bacteria varied considerably with the depths of water column. However, there was no distinct tendency of the vertical distribution of nitrate-reducing bacteria and denitrifying bacteria; The depth of water column showing maximum bacterial occurrence and maximum ratio varied from one station to another. Relatively high counts (10^2 celles/ml) of denitrifying bacteria were observed at stations 8, 13 and 15, respectively.

Acknowledgments

The authors are grateful to Captain T. JINNO as well as the other officers and crew of the training ship Seisui-Maru, Mie University for collecting seawater and sediment samples.

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