ISSN 0026-2617, Microbiology, 2009, Vol. 78, No. 6, pp. 798–801. © Pleiades Publishing, Ltd., 2009.
Original Russian Text © A.S. Savvichev, N.A. Demidenko, I.I. Rusanov, E.E. Zakharova, E.F. Veslopolova, I. Afonina, I. Ankudinova, N.V. Pimenov, M.V. Ivanov, 2009, published in Mikrobiologiya, 2009, Vol. 78, No. 6, pp. 840–843.

SHORT COMNMUNICATIONS

Study of the Microbial Processes in the Water Column and Bottom Sediments of the Dolgaya-Vostochnaya Bay (Barents Sea) before Construction of the Northern Tidal Power Plant

A. S. Savvichev[a,1], N. A. Demidenko[b], I. I. Rusanov[a], E. E. Zakharova[a], E. F. Veslopolova[a], I. Afonina[c], I. Ankudinova[c], N. V. Pimenov[a], and M. V. Ivanov[a]

[a] *Winogradsky Institute of Microbiology, Russian Academy of Sciences, pr. 60-letiya Oktyabrya 7, k. 2, Moscow, 117312 Russia*
[b] *State Oceanographic Institute, Rosgidromet, Kropotkinskii per. 6, Moscow, 119034 Russia*
[c] *Nanogen Inc., 21720 23rd Drive SE, Suite 150, Bothell, WA 98021, United States*

Received March 19, 2009

DOI: 10.1134/S0026261709060186

Tidal power plants (TPP) are alternative sources of energy production. Long-term observations of the TPP at the Kislaya Bay on the Barents Sea and the Rance TPP on the Atlantic coast of France [1, 2] indicate that the construction and operation of the Northern TPP (Dolgaya-Vostochnaya Bay) may change the current state of this water basin. Possible adverse effects may include contamination of the near-bottom horizon with sulfide due to the activity of sulfate-reducing bacteria. Activation of sulfate reduction has been described for a number of marine environments in various degrees of isolation from the offshore waters [3–8]. The disturbance of the operating regime at the Kislogubskaya TPP from 1974 to 1982, which resulted in a decrease in the water exchange with the sea to 2–3% [1], is a perfect example of rapid environmental change. Limitation of water exchange resulted in severe demineralization of the 15-m surface horizon, decreased mixing of the water column, and accumulation of sulfide at depths below 20 m, resulting in mass death of benthic animals.

The aim of the present work was to obtain a range of quantitative characteristics of the microbial processes of the carbon and sulfur cycles occurring in the water column and bottom sediments of the Dolgaya-Vostochnaya Bay before the construction of the Northern tidal power plant. No microbiological and biogeochemical investigations have been previously carried out in the Dolgaya Bay.

Samples for analyses were obtained during short-distance cruises of the R/V *Rostislav* (June and August, 2008). The hydraulic grade line of the Dolgaya Bay was studied from the apex to the sill. Water samples were collected with a Niskin bottle, whereas the bottom sediments were sampled with a stratometer. All experiments with water and sediment samples were carried out within 1 hour after sampling. The total number and production of bacterioplankton, as well as the rates of microbial processes of methanogenesis and sulfate reduction were determined using the methods previously described in [9]. The numbers of sulfate-reducing bacteria and methanogenic archaea were determined by inoculation of water aliquots into selective media [10, 11]. Taxonomic groups were identified using molecular diagnostic techniques (real-time PCR) [12].

The Dolgaya-Vostochnaya Bay is located in the Murmansk oblast (southern Barents Sea). The bay represents an extended fiord-like gulf (fiard) which projects into the northern coast of the Kola Peninsula for 5.5 km. The bay estuary is open, about 800 m long and up to 30 m deep; at the apex, the bay expands to about 1.5 km. The average width of the water area of the bay is 0.65 km, the average depth is 40.7 m, and the maximum depth is 96 m. The Dolgaya River and a small creek flow into the southern part of the fiard. With the high tide, the water area of the bay is 5.6 km^2.

Our studies demonstrated that the slightly freshened layer of the water column (32.6‰) corresponds to the 10-m surface layer. The halo- and thermocline are poorly defined and are located at a depth of 20–30 m (Table 1). In the lower horizons, temperature decreases and salinity increases, reaching 3.5°C and 35.05‰, respectively, in the near-bottom layers. The O_2 concentration in the surface layer was 10.7–10.9 mg/l, and it decreased with depth to 7.67 mg/l in the near-bottom horizon. The concentration of dissolved methane in the surface horizon was close to equilibrium with the methane concentration in the near-water atmosphere; local maxima were observed in the thermocline, as well as in

[1] Corresponding author; e-mail: savvichev@mail.ru

Table 1. Hydrological and hydrochemical characteristics of the water column of the Dolgaya-Vostochnaya Bay according to the survey results obtained in July and August 2008

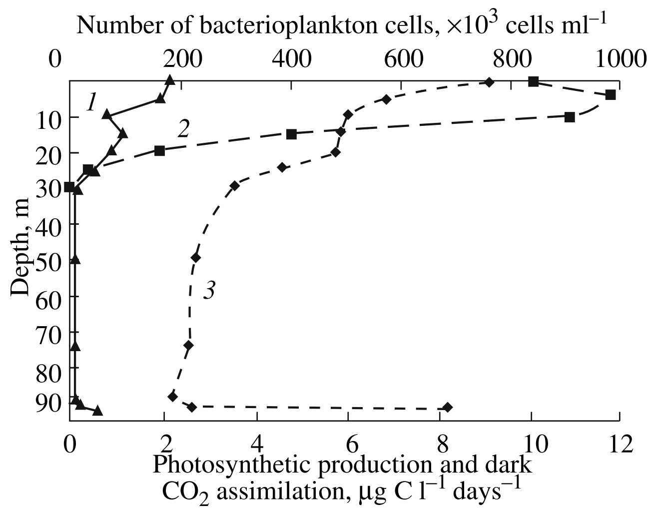
Station no.	Horizon, m	21st–23rd/06/2008 and 21st–22nd/08/2008					
		T, °C	S (‰)	O_2, mg/l	O_2 (%)	CH_4, nl/l
7	0	7.3/11.60	32.2/32.66	10.9/10.86	123	80/81
	5	ND/9.25	ND/34.18	ND/10.50	114	ND/90
	10	7.1/8.50	34.1/34.31	10.5/10.27	109	140/137
	15	ND/8.20	ND/34.35	ND/10.50	111	ND/160
	20	6.4/8.05	34.2/34.38	9.8/10.74	113	120/144
	25	ND/6.70	ND/34.54	ND/10.44	107	ND/137
	30	5.8/5.50	34.4/34.60	9.8/10.38	103	60/105
	50	4.1/4.10	34.5/34.63	9.4/9.44	91	50/72
	75	ND/4.10	ND/34.67	ND/9.09	88	ND/61
	90	ND/3.90	ND/34.83	ND/8.85	85	ND/82
	92	ND/3.80	ND/35.02	ND/8.67	83	ND/95
	93	3.5/3.80	35.1/35.05	8.4/7.67	73	280/160
11	0	6.5/10.20	32.0/32.83	10.8/10.97	120	70/88
	30	5.1/4.10	34.1/34.35	9.5/9.56	92	100/57
	68.2	3.8/3.80	34.5/34.43	8.4/9.44	90	120/95
12	0	6.09/9.85	32.2/33.44	10.7/10.92	119	70/76
	30	5.7/5.70	34.3/34.18	10.0/10.50	105	90/70
	58.2	3.5/3.50	34.4/34.62	8.8/9.74	92	140/82

Note: ND – no data.

the narrow near-bottom horizon (Table 1). Observations in June and August revealed no significant differences in the fundamental characteristics of the thermohaline structure.

In August, the highest rate of photosynthetic production (9.9–11.7 μg C l^{-1} day^{-1}) was detected in the 10-m surface horizon; it then gradually decreased to the minimal values (0.38 μg C l^{-1} day^{-1}) at 30-m depth (figure). The total photosynthetic production was 215 mg C m^{-2}, which allows us to classify the bay as mesotrophic. The total number of bacterioplankton in the surface layer was rather high, 570–760 × 10^3 cells ml^{-1}; below a depth of 20 m, it decreased from 470 to 200 × 10^3 cells ml^{-1}. In the near-bottom horizons (10–20 cm above the sediment surface), the number of bacterial cells increased dramatically up to 680 × 10^3 cells ml^{-1}. The rate of dark CO_2 assimilation (DA), which is considered an index of the total (autotrophic and heterotrophic) microbial activity, also was highest in the upper 20-m water layer. In deeper horizons, DA values decreased sharply and did not change significantly (0.10–0.20 μg C l^{-1} day^{-1}) down to the near-bottom horizon. All measurements indicate that, in the fiard basin, the production rates for phyto- and bacterioplankton in August are moderate. The significant activity of the processes was detected in the surface horizon, the thermocline, and the near-bottom water layers.

Bottom sediments of the deepest depressions in the Dolgaya-Vostochnaya Bay were represented by aleuric sediments laced with sand. The redox potential varied



Number of bacterioplankton cells, photosynthetic production, and dark CO_2 assimilation rate in the water column of the Dolgaya Bay: dark CO_2 assimilation, μg C $l^{-1}day^{-1}$ (*1*); photosynthetic production, μg C l^{-1} day^{-1} (*2*); number of bacterioplankton cells, × 10^3 cells ml^{-1} (*3*).

Table 2. Rates of microbial processes in the bottom sediments of the Dolgaya-Vostochnaya Bay according to the survey results obtained in July and August, 2008

Station no. (depth, m)	Horizon, cm	21st–23rd/06/2008 and 21st–22nd/08/2008				
		Eh, mV	$[CH_4,]$ μl dm^{-3}	DA, μg C dm^{-3} day^{-1}	MG, μl CH_4 dm^{-3} day^{-1}	SR, μg S dm^{-3} day^{-1}
7 (93)	0–1	160/120	25/19	110/253	1.2/0.89	8.0/13.5
	2–6	90/100	32/23	190/356	1.6/1.99	68/171
	6–10		ND/21	ND/364	ND/1.87	ND/46
11 (69)	0–3	140/ND	5/ND	204/ND	0.86/ND	37/ND
	3–8	100/ND	7/ND	255/ND	0.69/ND	54/ND
12 (59)	0–3	180/ND	5.5/ND	46/ND	0/ND	35/ND
	3–8	120/ND	9/ND	75/ND	0/ND	45/ND

Notes: $[CH_4]$, CH_4 concentration; DA, dark CO_2 assimilation; MG, methanogenesis rate; SR, sulfate reduction rate; ND, no data.

from +90 to +140 mV. The rates of sulfate reduction and methanogenesis mediated by obligately anaerobic bacteria and archaea are shown in Table 2. These rates corresponded to the average values typical of the near-shore sediments of the Western Arctic seas [13]. Using molecular techniques, it was shown that anaerobic microorganisms inhabiting the surface horizon (0–6 cm) of bottom sediments were represented by bacteria and archaea of the genera *Desulfovibrio* (100 units), *Methanosarcina* (10 units), *Methanogenium* (1 unit), and *Methanobacterium* (0.1 units, unstable detection). The growth of sulfate-reducing bacteria (1–10 cells/g sediment) was detected on selective nutrient media, while no growth of methanogenic archaea was detected.

This study demonstrated that, in the water column of the Dolgaya-Vostochnaya Bay, significant microbial activity occurs only in the photic layer. The numbers of microorganisms and DA intensity decrease at depths below 30 m (figure). Thus, a relatively high concentration of dissolved oxygen (up to 83–91% of the saturation level) were detected down to the near-bottom horizon even at the end of August (Table 1). In the bottom sediments, anaerobic microorganisms were detected. Radioisotope investigations revealed active development of sulfate-reducing bacteria and methanogenic archaea (Table 2). The presence of methane in all water samples with its highest concentrations in the near-bottom horizons is a direct indication of methanogenic activity. The decreased oxygen content (Table 1) and the increased DA intensity (figure) in the samples taken from the near-bottom horizons can serve as circumstantial evidence of the penetration of reduced products of microbial metabolism from the sediments into the near-bottom water layers.

The negative scenario possible after the TPP construction results in development of anaerobic conditions in the water column, and it may include disturbance of the current balance of the fresh- and seawater influxes. Significant demineralization of the upper horizons of the water column, together with a decreased rate of the water column mixing will result in dissolved oxygen deficiency and, after the exhaustion of oxygen, in sulfide production both in the water column and in the bottom sediments.

The paper does not call for the abandonment of the Northern TPP project. The engineering principles of the dam structure should allow for maximal preservation of the natural water exchange and regular washout of the isolated basin. The data obtained will be a starting point in the studies of changes in the functioning of the microbial community inhabiting the Dolgaya-Vostochnaya Bay.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (projects nos. 08-04-00248-a and 09-04-10035-k), by the program "Molecular and Cell Biology" of the Presidium of the Russian Academy of Sciences, and by the program "Leading Scientific Schools" of the President of the Russian Federation (grant no. 4174.2008.4).

REFERENCES

1. Marfenin, N.N., Malyutin, O.I., Pantyulin, A.N., Pertsova, N.M., and Usachev, I.N., *Vliyanie prilivnykh elektrostantsii na okruzhayushchuyu sredu.* (Environmental Effects of Tidal Power Plants), Moscow: MGU, 1995.
2. Clavier, J., Lechapt, J.-P., Retiere, Ch., and Rivain, V., Effects a long terme du fonctionnement de l'usine maremotrice sur l'evolution du peoplement des sables fins vaseux de la Rance, *Oceanol. Acta*, 1983. NSP. p. 75–79.
3. Semenov, V.N., *Sistematika i ekologiya morskikh basseinov Severa na raznykh etapakh izolyatsii.* (Taxonomy and Ecology of the Northern Marine Reservoirs at Different Stages of Isolation), Apatity: MMBI KF AN SSSR, 1988.
4. Deryugin, K.M., *The Mogil'noe Relic Lake*, Tr. Petergof Est.-Nauchn. In-ta, 1925, no. 2, pp. 1–112.
5. Ivanov, M.V., Rusanov, I.I., Pimenov, N.V., Bairamov, I.T., Yusupov, S.K., Savvichev, A.S., Lein, A.Yu., and

Sapozhnikov, V.V., Microbial Processes of the Carbon and Sulfur Cycles in Lake Mogil'noe, *Mikrobiologiya*, 2001, vol. 70, no. 5 [*Microbiology* (Engl. Transl.), vol. 70, no. 5, pp. 583–593].

6. Dyrssen, D.W., Hall, P.O.J., and Haraldsson, C., Time Dependence of Organic Matter Decay and Mixing Process in Framvaren, a Permanental Anoxic Fjord in South Norway, *Aquatic Geochem.*, 1996, vol. 2, pp. 111–129.
7. Ivanov, N.O., Kitaev, S.P., and Chechenkov, A.V., *Osobennosti gidrofauny Kanda-guby Belogo morya* (The Hydrofauna of the Kanda Bay, White Sea), Leningrad: ZIN AN SSSR, 1983.
8. Nimburg, E.A., The Dolgaya Bay: Natural and Artificial Isolation, *Priroda*, 1990, no. 7, pp. 44–49.
9. Savvichev, A.S., Rusanov, I.I., Pimenov, N.V., Zakharova, E.E., Veslopolova, E.F., Lein, A.Yu., Ivanov, M.V., and Krein, K., Microbial Processes of the Carbon and Sulfur Cycles in the Chukchi Sea, *Mikrobiologiya*, 2007, vol. 76, no. 5, pp. 682–693 [*Microbiology* (Engl. Transl.), vol. 76, no. 5, pp. 603–613].
10. Widdel, F., The Genus *Desulfotomaculum*, in *The Prokaryotes, 2nd ed.*, Balows, A., Trüper, Y.G., Dworkin, M., and Harder, W., Eds., New York: Springer, 1992, vol. 2, pp. 1792–1799.
11. Zeikus, J.G., Weimer, P.J., Nelson, D.R., and Daniels, L., Bacterial Methanogenesis: Acetate as a Methane Precursor in Pure Culture, *Arch. Microbiol.*, 1975, vol. 104, pp. 129–134.
12. Afonina, I., Mills, A., Sanders, S., Kulchenko, A., Dempcy, R., Lokhov, S., Vermeulen, N.M.J., and Mahoney, W., Improved Biplex Quantitative Real-Time Polymerase Chain Reaction with Modified Primers for Gene Expression Analysis, *Oligonucleotides*, 2006, vol. 16, no. 4, pp. 401–409.
13. Savvichev, A.S., Rusanov, I.I., Zakharova, E.E., Veslopolova, E.F., Mitskevich, I.N., Kravchishina, M.D., Lein, A.Yu., and Ivanov, M.V., Microbial Processes of the Carbon and Sulfur Cycles in the White Sea, *Mikrobiologiya*, 2008, vol. 77, no. 6, pp. 823–838 [*Microbiology* (Engl. Transl.), vol. 77, no. 6, pp. 734–750].