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Nutrient-Abundant Natural Waters of Arctic Mountain Tundra, North-Eastern Siberia

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Abstract: Natural waters of the spacious Arctic regions of Russia are studied insufficiently and they are still opened to the most important questions. This paper presents the results of in situ hydrochemical study of a small catchment in Arctic mountain tundra of the Koryak Highland, north-eastern Siberia, situated far from industrial centres and populated territories. The results showed a surprisingly high content of inorganic nutrients in natural waters—stream, swampy and rainy. For the basin main water collector—the Levtyrinyvayam River—it was as following (μM): NO_3^--N (134±66), NO_2^--N (1.1±0.4), NH_4^+-N (11.1±5.6), PO_4^{3-}-P (2.42±1.79) and K^+ (31±36), indicating the intensive organic matter decomposition and the nutrient saturation in the local terrains. Specific conditions of the mountain ecosystem, *i.e*. contrast soils, and influence from shallow-lying permafrost resulted in the rate of the nutrients' saturation of the waters. The results prove the great importance of organic matter and its derivatives in investigation of natural waters.

Key words: Nutrients, nitrogen, Arctic mountain tundra, natural waters, small catchment, Koryak Highlands.

Introduction

In recent decades, we have become aware of the increasingly destructive intrusion into the Arctic regions of Russia; mostly because the intensive gold-mining that often causes major imbalances of these frangible ecosystems and disturbance of the indigenous population habitat. Moreover, the problem of climate change consequences in the Arctic has merged recently. Therefore, it seems vital to obtain reliable information regarding biogeochemical peculiarities of Arctic natural waters. Natural waters of the spacious and sparsely populated Arctic regions of Russia are studied insufficiently. In particular, information on nutrient and organic matter constituents is rough so far and is based mostly on single-point measurements. Also, the available published data is often considered untrustworthy due to questionable reliability of instrumentation, and poorly executed quality control common to the Russian water monitoring programme (Tsirkunov, 1998; Dittmar and Kattner, 2003). Lack of exact specification for the methods used as well as the time interim from sampling till analysis is regrettable aggravation for the most published works. That is why hydrochemistry of tundra natural waters is still open to the most important questions (Perelman, 1975, 1982; Holmes et al., 2000).

As Perelman (1975) noted, tundra is a product of cold and wet climate, specifically a cold and wet summer; the amount of solar radiation is equal to that of the southern taiga, but the summer air temperature is much lower. That is why the rate of organic matter decomposition is *a priori* supposed to be low, resulted in accumulation of the

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so-called “rough humus” (Targulian, 1971; Perelman, 1975; Post et al., 1982). Many authors stressed the importance of organic matter and its derivatives in the Arctic natural waters. Nitrogen and phosphorus are supposed to be principally discharged in the form of organic compounds, while the concentration of inorganic nutrients reported is among the lowest worldwide (N: 0-20 µM; PO_4^{3-}-P: 0-0.8 µM) (Dittmar and Kattner, 2003). The summarized data for some major rivers of the tundra zone is available from Meybeck (1979, 1993).

This paper presents the results of an in situ summer hydrochemical survey in a small catchment of mountain tundra of the Koryak Highland, north-eastern Siberia. Most measurements were carried out directly in water objects or immediately after the sampling. Consequently, such data, obtained from the measurements in samples not exposed to any storage or transportation, are supposed to reflect the natural hydrochemical situation. Furthermore, it is known that the hydrochemical response represents an integration of hydrologic and biogeochemical reactions within catchment ecosystems. Thus, nutrients carried by rivers are important indicators of biogeochemical processes in the catchments.

Objects and Methods

Study Site

The 44 km long Levtyrinyvayam (Latyrinvayam) river is a tributary of the Vyvenka river that runs into the western Bering sea. The location of the survey is presented in Figure 1. The Levtyrinyvayam river drains some 228 km^2 of the Vetvey Ridge southern flanks. Mountain goletz-lichen and dwarf-pine tundra terrains occupy most elevations and middle slopes of the catchment, while waterlogged hummocky and peaty terrains constitute stream-bed valley. The average annual temperature is +2.9°C. The precipitation is some 400-550 mm and exceeds evaporation by 100-200 mm. Permafrost is continuous everywhere (Targulian, 1971; Project…, 1994). The relief is highly dissected and about 1/3 of the lower river course lies within the waterlogged depression. Tundra podbur soils formed on the light and rubbly rocks of the eluvial part of the catena and tundra gley soils of the lower accumulative part are the principal soil types. The water discharge is formed mostly by snow melt and rains, and—to a lesser extent—by groundwater (Project…, 1994). The basin is scarcely populated and is distant from the centres of economic activity. However, residual Far-East monsoons, carrying air masses from the Yellow and Japan Seas, influence the area. A platinum-mining artel is the only commercial enterprise in the area.

Figure 1: Scheme showing the survey location.

For the present study water was sampled: (1) at a stationary point in the middle (the lower mountain) part of the Levtyrinyvayam river, and its two tributaries draining (2) swamp mass in the bed-valley, and (3) barren of vegetation and lichens talus slopes of the ultra-basic Seinav massif. Samples of water of (4) two rains were also taken for analyses.

Methods

The water was filtered and analysed immediately by means of the field photocolorimeter DR/1A (Hach Company, USA) for the following parameters: apparent colour, turbidity, total hardness, Fe total, SO_4^{2-}, NO_3^-, NO_2^-, NH_4^+, SiO_2 reactive, and PO_4^{3-} reactive. HCO_3^- was determined titrimetrically. Na^+, K^+, Ca^{2+} and Mg^{2+} were analysed by flame photometry on returning to the laboratory. The above determinations were carried out in compliance with APHA methods (APHA, 1992), while NO_2^- was done by the diatization method (USEPA, 1983). A set of portable field devices from Central Kagaku (Japan) allowed measuring some parameters directly in water, viz. temperature, O_2, pH, Eh, conductivity and Cl^-.

Results and Discussion

According to the classification of natural waters after Perelman (1975, 1982), water of the Levtyrinyvayam river may be characterised as following: cold, oxidising, O_2 saturated, alkalescent, ultra-fresh, low and unsteady in content of colour organic matter. The content of so-called “major” ions was: hydrocarbonate (69% HCO_3^- as C, of total anions), nitrate (as N, 15%), siliceous (as

Si, 14%), and sodium (41% of total cation content), calcium (31%), magnesium (18%) and potassium (6%) (Table 1, Figure 2).

The most impressive data have been obtained for the nutrients: with a surprisingly high concentration of PO_4^{3-}, K^+, NH_4^+, NO_2^- and NO_3^- determined for the waters of the Levtyrinyvayam river and its two tributaries - (1) from the swampy mass and (2) talus of the Seinav mountain massif, and rain water (Table 2). The values obtained are extremely high as compared to the data for the large Arctic rivers in lowlands (Meybeck, 1979, 1993; Lara et al., 1998). The only reference for a small mountain catchment within the Russian sub-arctic zone was available to the authors for comparison: an in situ investigation of streams of the Uchur-Maya Highland,

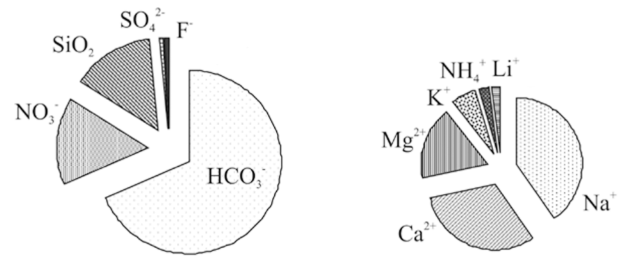

Figure 2: Ratio of "major" ions in water of the Levtyrinyvayam river.

eastern Yakutia gave 13-121 μM of NO_3^-, with maximum in the second half of summer, and 3.9-19.4 μM for PO_4^{3-} (Zuboirova and Neudachin, 2001). All the determinations were carried out a few hours after sampling. A

Table 1: Hydrochemical parameters of the small mountain tundra Levtyrinyvayam river compared to data for some small and major tundra rivers

Parameter	$x \pm S_x$	*Min-max*	*Major tundra rivers (Meybeck, 1979, 1993)*	*Lena river (Lara et al., 1998)*
Temperature, °C	9.5 ± 1.7	6.8-13.2		
Conductivity, mS cm^{-1}	0.061 ± 0.003	0.059-0.067		
Eh, V	0.48 ± 0.09	0.21-0.62		
pH	7.5 ± 0.2	6.9-7.7		
O_2 free, mg L^{-1}	12.7 ± 0.9	10.5-13.8		
CO_2 free, mg L^{-1}	5.5 ± 3.5	0.9-16.0		
Colour, °Pt-Co	18 ± 18	0-70		
Turbidity, mg L^{-1}	13 ± 21	0-70		
Σ ions, mg L^{-1}	57 ± 23	38-135		
Hardness total, mg eq L^{-1}	0.55 ± 0.25	0.15-1.08		
SiO_2, μM	271 ± 96	143-536		59-87
Fe total, μM	1.25 ± 0.89	0.53-4.82		
HCO_3^-, μM	514 ± 246	83-984	489	
SO_4^{2-}, μM	8.3 ± 11.5	0.0-26.0	60.4	
Cl^-, μM	1.13 ± 0.28	0.56-1.97	70.4	
F^-, μM	6.3 ± 3.2	0.0-12.6		
PO_4^{3-}, μM	2.4 ± 1.8	0.3-5.4	0.3, 3.9-19.4$^+$	
NO_3^-, μM	134 ± 66	32-256	7, 4.5-27*, 13-121$^+$	0.01-1.44
NO_2^-, μM	1.1 ± 0.4	0.2-2.0		0.03-0.1
NH_4^+, μM	11.1 ± 5.6	5.6-22.2	1.1	0.01-0.3
Ca^{2+}, μM	153 ± 103	25-415	194	
Mg^{2+}, μM	88 ± 87	26-160	89	
Na^+, μM	196 ± 139	30-287	(135)	
K^+, μM	31 ± 36	8-121	(8)	

*Alpine/Subalpine ecotone water streams, Colorado Front Range (Hood et al., 2003)
$^+$Uchur-Mayskoye Highland small streams, eastern Yakutia (Zuboirova and Neudachin, 2001)

Table 2: Inorganic nutrients of the streams, swampy drainage, and subsurface waters of the Levtyrinyvayam river catchment, μM

Parameter	*Levtyrinyvayam river (n=25), $x \pm S_x$*	*Swamp tributary (n=11)*	*Talus streams, Seinav Range (n=3)*	*Swamp drainage (n=3)*	*Swamp water (n=3)*	*Rain water (n=3)*
Temperature, °C	9.5±1.7	4.2-7.6	8.6-10.0	7.0-7.3	n.d.	n.d.
Conductivity, mS cm^{-1}	0.061±0.003	0.036-0.060	0.034-0.042	0.049-0.055	n.d.	n.d.
Eh, V	0.48±0.09	0.25-0.40	0.72-0.76	–0.15-0.21	–0.20-0.26	0.65-0.50
pH	7.5±0.2	7.0-7.3	7.7-8.3	6.0-6.2	5.9-6.3	6.3-6.0
O_2 free, mg L^{-1}	12.7±0.9	8.0-14.8	12.1-12.5	2.8-3.6	n.d.	n.d.
Colour, °Pt-Co	18±18	15-75	6-14	124-156	1300-1400	7-15
Turbidity, mg L^{-1}	13±21	14-70	0	113-139	850-880	0
Fe_{total}, μM	1.25±0.89	3.87-4.11	0.89-1.25	10.0-11.1	78.3-81.5	0.09-0.84
$PO_4^{3-}{}_{react.}$, μM	2.42±1.79	1.05-9.37	2.23-2.74	1.16-1.62	n.d.	3.11-3.41
NO_3^-, μM	134±66	32-256	26-34	63-76	123-134	64-136
NO_2^-, μM	1.09±0.4	0.48-2.62	0.37-0.49	0.65-0.81	1.30-1.44	0.30-0.46

n.d. = not determined for technical reasons or the results raised doubts.

comparable NO_3^- concentration was found for streams of high-elevation catchments of the Sierra Nevada (Sickman et al., 2002), alpine tundra within the Colorado rocky mountains and other mountain ecosystems (Williams et al., 1996; Fenn et al., 1998; Burns, 2004), even in areas dominated by parent rocks or talus deposits (Campbell et al., 2002).

Interestingly water of the stream draining talus of the ultra-basic Seinav massif turned to be also saturated with nutrients (Table 2). However, concentrations of NO_3^- and NO_2^- were noticeably lower compared to the Levtyrinyvayam river and its tributary from the swamp massif. The talus streams have their source at the sub-top of the mountain massif and they are fed, for the most probability, by melting crackish water, i.e. water originated primarily from atmospheric precipitation, then interacted with exposed rocks (olivine and serpentine), and transformed presumably by the specific microbial communities (Ley et al., 2004). The hydrochemical discharge with these streams may reflect the nutrients' impact with both monsoon rains and marine aerosols from the nearby sea.

The specific rate of inorganic N export from the catchment may be more indicative for the phenomenon discovered. This value estimated for the 1.5 month period investigated was high: nearly 0.26 kg ha^{-1}, including 0.24 NO_3^--N kg ha^{-1}, 0.02 NO_2^--N kg ha^{-1}, and 0.002 NH_4^+-N kg ha^{-1}, i.e. nearly 92.3, 7.7 and 0.8% of total N, accordingly. Unfortunately, there is no reliable base to estimate what portion of the year this inorganic nutrient was discharged. Nevertheless, according to the published data (Targulian, 1971; Holmes et al., 2000) more than 90% of the Arctic annual water delivery occurs from May to July. From this, in a rough estimate—if we consider the values obtained for the catchment as only 1/10 of the annual discharge—it would be on the maximum level of values reported for nitrate leaching from boreal forests. These values are less than 1 kg N ha^{-1} yr^{-1} for coniferous forests, somewhat higher in deciduous forests, but usually less than 2-3 kg N ha^{-1} yr^{-1} (Gundersen and Bashkin, 1994; Persson et al., 2000). For example, stream waters within the Colorado Front Range yielded NO_3^--N from 4.3 kg ha^{-1} in the alpine terrains to 0.75 kg ha^{-1} at sub-alpine forested ones, decreased downstream (Hood et al., 2003).

This phenomenon of the nutrient saturation might be attributed to specific biogeochemical processes in the local mountain tundra ecosystems. As Campbell et al. (2002) reported, measurements of $\delta^{18}O$-NO_3^- indicated that even during snowmelt much of the NO_3^- originated from nitrification in soils. Soil processes might stimulate energetic decomposition of litter and soil organic matter and of nutrient component accumulation, followed by subsequent unloading into surface waters. Washing-out of ingredients, accumulated during winter organic matter decomposition, might also be important (Hobbie and Chapin, 1996). For example, as Kendall (1998) and Campbell et al. (2002) have shown, most of N eluted from the snow blanket appears to be taken up in catchment soils and/or vegetation, and the stream N pulse is derived primarily from the flushing of biologically transformed N from catchment soils. Recent research in the Colorado Rockies has shown that a N saturation model, which was originally based largely on data from forested ecosystems, also describes the patterns of NO_3^- leaching observed in alpine ecosystems (Burns, 2004).

Symptoms of N saturation are widespread in the North American (Fenn et al., 1998) and European (Gundersen et al., 1998) forest ecosystems, mostly in mountain areas. Human alteration of the N cycle that has increased dramatically in recent years is supposed to be the main reason of the phenomenon (Vitousek et al., 1997). Some natural ecosystems with little human disturbance and low anthropogenic N inputs exhibit the symptoms of N saturation (Stottlemyer, 1992; van Miegroet et al., 1992). Moreover, high-elevation catchments are supposed to have insufficient capacity for N consumption in terrestrial systems to prevent the appearance of N in aquatic systems, because of combination of N release from snow, a limited growing season (reduced plant N demand), and poorly developed soils (Baron et al., 1996), reduced contact time between drainage water and soil (i.e., porous coarse-textured soils, exposed parent rocks or talus) (Fenn et al., 1998).

Some more factors may play a determinative role in the local terrain processes. It is known that the most favourable factors leading to the soil organic matter decomposition/N saturation and nitrate/nutrients leaching are as follows: sufficient warming, O_2 saturation, high redox-potential and precipitation surplus (Perelman, 1975; Gundersen and Bashkin, 1994; Persson et al., 2000). In particular such conditions take place in the tundra podbur soils of the elevated eluvial terrains that are easily drained from surplus snow, melting permafrost and rainy waters. Aerobic regime and oxidising conditions, intensive circulation of soil solutions, and the downward migration with surface and intra-soil waters during the warm season prevail in these soils. The waters wash the soil profile through and carry dissolved and suspended ingredients down the catena (Targulian, 1971). Thus, there is no limitation of soil processes from such factors as light, moisture and temperature in the catena elevations, while such limitation is common in alpine tundra of lower altitudes.

On the other hand, denitrification processes might alleviate effects of excess N in the terrains. These processes are ascertained to be effective in conditions of low Eh (Gundersen and Bashkin, 1994; Persson et al., 2000). Exactly such conditions can be found in tundra gley soils of stream-bed valleys. These soils, in contrast to the podbur soils of elevation, can never be warmed up enough to produce optimal conditions for microbial activity, as they are recharged and influenced by the shallow-lying permafrost layers. Here the waterproof icy permafrost strata lie at maximum 60-80 cm depth even in late August, creating conditions of soil cooling, over-moistening, and presence of cooled temporary perched ground waters (Targulian, 1971). Consequently, it may be supposed that such specific temperature regime may restrain denitrification and nutrient utilisation in the lower accumulative part of the catena as well as in the cold water of the local streams and swampy terrains.

Williams et al. (1996) marked a lack of process-level understanding of the N biogeochemical cycle. Since N concentrations in surface waters are generally consistent with the release of NO_3^- from storage in the seasonal snow blanket and the NO_3^- in stream waters is often assumed to be from wet and dry deposition. However, experiments conducted by Kendall et al. (2002) indicate that about half or even greater of the NO_3^- in alpine stream water was the product of microbial activity. In our case, high concentrations of PO_4^{3-} and K^+ in waters of the Levtyrinyvayam river basin allow to suggest the same microbial activity-conditioned mechanism for N and other nutrients' release to the Arctic mountain tundra natural waters.

Moreover, one can see that the Arctic tundra waters could not be characterised with routine "major ions" schemes that consider usually HCO_3^-, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, pH and some other parameters. In fact, to say that the waters of the Levtyrinyvayam river catchment are hydrocarbonate-sodium-calcium means to say nothing. Such characteristic is entirely insufficient for understanding of the real nature of the complicated and living ecosystem-dependant natural body as natural waters are. Knowledge of organic matter transformation and its organic and inorganic derivatives, including dissolved gases, redox processes, etc. should be considered in hydrochemical investigations (Perelman, 1982).

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