Bulgarian Rila Mountain Forest Ecosystems Study Site: Site Description and SO_4^{2-}, NO_3^- Deposition[1]

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Abstract
*Bulgaria's forest ecosystems (31 percent of the country's area) are considered vulnerable to dry and wet pollution deposition. Coniferous forests that cover one-third of the total forest land are particularly sensitive to pollution loads. The USDA Forest Service, Sofia University, and the Bulgarian Forest Research Institute (FRI) established a cooperative program to study a Rila Mountain forest ecosystem site, its climatology, air quality, surrounding watershed, hydrology, and soil characteristics. The cooperative program was initiated in September 1991 by upgrading an existing climatology site: Ovnarsko no.3 in the Govedartsi Valley on the north slope of the Rila Mountains. The dominant tree species surrounding the site include Scotch pine (*Pinus sylvestris *L.), black pine (*Pinus nigra *Arn.), Norway spruce (*Picea abies *Karst.), white fir (*Abies alba *Mill.), beech (*Fagus sylvatica *L.), and several oak species (i.e.,* Quercus petraea *Liebl,* Q. pubescens *Willd.,* Q. conferta *Kit.,* Q. cerris *L., and* Q. robur*). Weekly concentrations of nitrate, sulfate, sulfur dioxide, calcium, sodium, and potassium were measured using a filter-pack technique. Data for 18 weeks between October 1991 and November 1993 were collected. Annual acidic aerosol deposition values for 1992 and 1993 were estimated for SO_4^{2-}, which was slightly above 3 kg ha^{-1} yr^{-1}, and for NO_3^-, which decreased from 1.3 to 0.3 kg ha^{-1} yr^{-1}.*

Introduction
The Bulgarian Higher Institute of Forestry (HIF), Govedartsi Valley forest meteorological monitoring site, Ovnarsko no. 3, was upgraded in September 1991 (Zeller 1991). The manual recording protocol was enhanced to include continuous hourly measurements of standard meteorology and a filterpack system to determine pollutant dry deposition by direct measurements (Zeller and others 1992). A memorandum of understanding, MU RM-93-164, entitled "Atmospheric Interaction with Natural Ecosystems in Bulgaria and the U.S.A." was executed in July 1993 between the Bulgarian Forest Research Institute (FRI), Sofia University Department of Meteorology (SUDM), and the USDA Forest Service's Rocky Mountain Forest and Range Experiment Station (RMFRES) to formalize the cooperative effort.

This paper describes the Rila Mountain forest ecosystem site in Bulgaria and its surrounding watershed, location, forest, hydrology, geology, soils, and climate by using land manager's records and the European International Food and Agriculture Organization (FAO) system (Bojinov 1981, FAO 1989); and it presents sulfate and nitrate measurements resulting from the cooperative effort.

Location and Methods
Bulgaria is located in the southeastern part of the Balkan peninsula south of Romania, east of the Black Sea, north of Greece and west of Serbia. Forests cover about 33,300 km^2, 31 percent of the country's area. About 37 percent of the forested area is occupied by coniferous forests, 19 percent by seed-originated broad-leaved stands, and 44 percent by deciduous coppices of low productivity. The dominant tree species include Scotch pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* Arn.), Norway spruce (*Picea abies* Karst.), white fir (*Abies alba* Mill.), beech (*Fagus sylvatica* L.), and several oak species (i.e. *Quercus petraea* Liebl, *Q. pubescens* Willd., Q. *conferta* Kit., *Q. cerris* Lq., and *Q. robur*).

Ovnarsko no. 3 (elevation 1,600 m) is located 4 km west of Govedartsi, Bulgaria, situated on the north slope of the Rila Mountains (see site map in Donev and others, this volume). Govedartsi (cattle place) is a small, agrarian village that sports

[1] An abbreviated version of this paper was presented at the USDA Forest Service International symposium on Air Pollution and Climate Effects on Forest Ecosystems, February 5-9, 1996, Riverside, California.

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a small commercial ski lift, Maljovica, 13 km southwest. Govedartsi is about 70 km south of Sofia, the capital city of Bulgaria, and 14 km southwest of Samokov, a small city. The climate discussion herein is specific to Ovnarsko no. 3. The forest, hydrology, geology and soils discussions are for the general area on the north slope of the Rila Mountains and Govedartsi Valley.

The northern slopes of the Rila Mountains are located in the south of Sofia County. The forested areas are managed by the Samokov and Borovets forest districts and are typical Bulgarian forest regions. In addition to Govedartsi are the small villages Madgare, Mala Tsarkva, Borovets, and Beli Iskar. The Borovets meteorological station location is also a famous all-season national resort of the same name. The general study area described here includes three parts of four north slope Rila Mountain morphographic spurs: Malyovishki (northwestern); Skakavishki (central); and Moussalevsni (eastern). The area has the shape of a leaf with its long fingers about 26 km long and about 12 km wide covering latitudes: 42°06' - 42°17' N; and longitudes 23°12' - 23°40' E. The terrain is very rugged, with clearly outlined hillsides and deeply incised rivers, streams, and ravines. Elevation of the area described is 1,050 - 2,200 m.

Ovnarsko Site Instrumentation Upgrade

Wind speed and direction, air temperature, and humidity sensors are installed at 5 m height; total solar radiation, wetness (actually psuedo-wetness: an electronic plate that simulates a leaf surface and records the value 1 when wet and 0 when dry), precipitation, soil temperature, and soil heat flux measurements are also collocated. Hourly means and variances of the measured quantities were recorded with a Campbell Scientific 21x data logger[6] at 0.1 hertz. Ozone was sampled during the spring and summer months of 1994 and 1995 (Donev and others[this volume]) at 2 m height (*table 1*).

***Table 1** – Parameters measured at the Ovnarsko site.*

Sensor	Parameter	Period	Units
Filter Pack	SO_4^{2-}	week	μg m^{-3}
Filter Pack	NO_3^-	week	μg m^{-3}
Filter Pack	Mg^{2+}	week	μg m^{-3}
Filter Pack	Ca^{2+}	week	μg m^{-3}
Filter Pack	Na^+	week	μg m^{-3}
Filter Pack	K^+	week	μg m^{-3}
Dasibi 1000H	Ozone	hour	ppb
Pump flow	Sample volume	hour	liter pm
MetOne, Inc	Wind direction	hour	Degree, Deg^2
MetOne, Inc	Wind speed	hour	m s^{-1}, m^2s^{-2}
Eppley	Solar radiation	hour	watt m^{-2}
MRI Inc.	Precipitation	hour	mm
MetOne, Inc.	Temperature	hour	°C
MetOne, Inc.	Relative humidity	hour	pct
Rad Energy	Soil heat flux	hour	watt m^{-2}
thermocouple	Soil temperature	hour	°C
thermocouple	Soil °C gradient	hour	°C
Campbell Sc.	Pseudo wetness	hour	wet:1;dry:0

[6] Mention of trade names or products is for information only and does not imply endorsements by the U.S. Department of Agriculture.

Particulate and Gaseous Ambient Concentration

Pollutant concentration measurements were made by drawing ambient air at the rate 2.0 ± 0.2 liters per minute (24 hr day^{-1}, multi-day $period^{-1}$) through a three-stage filter pack mounted on the meteorology mast at 4 m above ground level. The filter pack system was designed and supplied by the U.S. National Biological Service/ Environmental Science and Technology Center (ESTC). The filter pack inlet is 0.95 cm in diameter, which allows for the collection of aerosols smaller than about 10 mµ diameter when oriented downward. The filter pack itself was mounted under a 20.3 cm diameter polyvinyl chloride (PVC) rain shield. Air flow is volumetrically controlled with a diaphragm pump, pelton-wheel flow meter. Filter packs were exchanged periodically as indicated in the record.

Filter packs provide a convenient, low-cost method for measuring acidic air pollutants (Anlauf and others 1985). Various acid gases and particles are retained on the stacked filters. Wet chemistry extraction of the filtered material yield pollutant masses. The filter pack chemistry used at the Ovnarsko site is the same used for the U.S. Environmental Protection Agency National Dry Deposition Network (NDDN) (Edgerton and others 1989). Three filters are placed in series within an inert Teflon holder: first, teflon "Zeflour" 2µm filter traps suspended particulate aerosols; next, a nylon "Nylasorb" 1µm filter absorbs acidic gases such as nitric acid and sulfur dioxide; and last, two Whatman 41 ashless cellulose filters infuse a 25 percent K_2CO_3 solution and glycerol SO_2 is oxidized to SO_4^{2-} when passed over K_2CO_3, and retained as SO_4^{2-} on the Whatman filters (Zeller and others 1996).

Filter pack preparation, extraction, and analysis was accomplished by a Bulgarian Laboratory under the supervision of the FRI as outlined in the "NDDN Laboratory Operations Manual" (Hunter/ESE 1989). Filter specific laboratory species weights are divided by the measured air volume that passed through the filter pack to provide average concentrations: SO_4^{2-} (teflon filter SO_4^{2-} mass) and NO_3^-(teflon filter NO_3^- mass).

Record Data

Forest

Rila Mountain northern slope forests are mostly indigenous conifers and are managed for timber production. Human occupations that have influenced forest health and use in the Rila Mountain area include iron and gold mining, range management, logging, agriculture, and in the past charcoal production associated with mining. The study area can be examined by forest activity, forest type, and density (*table 2*) (Bojinov 1981). Total timber production area is 16,845 hectares.

Table 2 *— Forest type, density, and area of the Rila Mountain site.*[1]

Type	Coniferous	Broadleaf	Total	Percent
Density 0.4-1.0				
Indigenous	13,641	556	14,197	73.2
Crop	590	50	640	3.3
Density 0.1-0.4				
Indigenous	1,696	30	1,726	8.9
Crop	51	0	51	0.3
Density 0.0				
Seeded	230	0	230	1.2
Dwarf pine	97		97	0.5
Bare lands	2,442		2,442	12.6

[1] ha

The majority of timber production occurs on slopes between 10 to 30 percent steepness (*table 3*). Bulgarian forests are also classified by slope orientation exposure: sunny (SE, S, SW, and W) 4,498 hectares (ha); and shady (NW, N, NE and E) 12,348 ha. *Table 4* gives a breakdown by elevation.

Table 3* — *Rila Mountain forest by area and slope.

Slope					
(percent)	0-4	5-10	11-20	21-30	>30
Area (ha)	152	977	6,081	7,901	1,735

Table 4* — *Rila Mountain forest by area and elevation.

Evevation					
Elevation(m)	<1,300	1,301-1,500	1,501-1,700	1,701-1,900	>1,900
Area (ha)	4,354	5,294	3,439	2,717	1,042

The main species composition of the study area include: Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), silver fir (*Abies alba*) and Macedonian pine (*Pinus peuce*). There are, however, 23 different coniferous species, including 10 *Pinus* species, and 54 different broad-leaved species including 8 *Acer* (Delkov 1988, Stefanov and Ganchev 1958). Sensitivity of these Bulgarian tree species to human activities has been expressed as the resistance of each tree species to air pollutants (Prokopiev 1978). *Table 5* (Bojinov 1981) gives the coverage area by main species and age.

Silver fir is most sensitive to environmental factors. It mostly inhabits cool sites where winter temperatures are moderate. It is particularly sensitive to extreme temperatures, especially spring frosts. Silver fir only occupies a small part of the study region: shady and semi-shady sites with mean annual temperatures between 4.5 and 7.5 °C.

Scots pine is a species with almost no sensitivity to particular environmental factors. It tolerates low tundra-like temperatures to high steppe-like temperatures. It withstands extreme temperatures and quickly colonizes bare areas.

Macedonian pine expresses itself as a native species. It demands high and permanent moisture, particularly high humidity. Macedonian pine trees usually grow in a narrow strip above 1,800 m where environmental conditions are favorable to their development or in areas with mean annual temperatures around 4 °C.

The range of Norway spruce coincides with that of silver fir. In the lower portions of the mountains, it begins at regions with mean annual temperatures of 6.5 °C and grows to elevations with mean annual temperatures of about 2.5 °C.

Table 5* — *Rila Mountain forest by age and coniferous type.

Type / Age (yrs.)	**0 - 40**	**40 - 80**	**80 - 120**	**120 - 160**	**Percent**
Scots pine (ha)	922	3,792	1,112	50	37
Norway spruce	593	1,629	2,796	329	31
Silver fir	25	297	824	21	7
Macedonian pine	185	669	1,117	99	13
Mixed coniferous	124	651	989	93	12

Hydrology, Geology and Soils

The headwaters of the Iskar and the Marica, Bulgaria's two longest rivers, are located within the study area. The Iskar flows north to the Duna (Danube) and the Marica flows southeast to Turkey and eventually the Aegean Sea. Numerous mountain lakes are situated deeply within the Rila alpine at elevations above the study site.

The Rila Mountains are composed of intrusive and metamorphic rocks. South Bulgarian granite is a representative for the first group and is the major component of the mountain core. This granite is found mostly in the south half of the study area just beneath the soil surface. Metamorphic rocks are found in the north half of the study area and are represented mainly by gneiss and schists. Sandstones and conglomerates are found to a lesser extent and lime rocks as well as mechanical sediments represented by gravels and sands also occur. The Rila Mountains were formed during the Paleozoic era (the Hercynian folding) and were strongly denuded in the Mesozoic era. In the beginning of the Tertiary, the study area experienced vertical movements that caused the formation of the surrounding kettle, such as the inner Govedarska Kettle Hole (Bojinov 1981).

The soils in the study area are humic, entric and distric cambisols (*table 6*). Humic cambisols, which are the deepest and most stony, are distributed in the form of a belt in the south portion of the study area above the granite. These soils occur mainly under stands of Macedonian pine and Norway spruce, and pure and mixed Norway spruce stands that comprise 5,027 ha or 30 percent of the study area timber. Entric cambisols, the next deepest and moderate to slightly stony, occupy 9,815 ha (58 percent of the timber area) and are located in the north and lower elevations of the study area above the gneiss. These soils are dominated by Norway spruce and silver fir with some Macedonian and Scots pines. Distric cambisols, which are only slightly stony, are situated mainly on south-facing slopes in the NW portion of the study area and total 2,004 ha (12 percent) of the timber with mostly Scots pine stands.

Moisture reserves in all north slope soils are favorable for tree vegetation and growth (*table 6*). These soils are also well-supplied with nutrients (humus and total nitrogen), especially the humic and entric cambisols (*table 6*). The acidity of distric cambisols varies within the narrowest range (5.2 to 5.4); humic cambisols (3.6 to 5.2) are similar but slightly lower compared to the entric cambisols (4.2 to 5.7).

***Table 6** — Average characteristics of soil types on the north Rila Mountain slopes (Bojinov 1981).*

Type	Depth/humus Horizon (cm)	Water capacity Total/active (mm)	Nutrient Humus/total N (t/ ha)	pH
Humic cambisol	90/35	433/382	442/17	4.4
Eutric cambisol	>80/25	393/359	426/20	5.0
Dystric cambisol	<80/<20	146/139	83/3	5.3

Climate

The climatology of Ovnarsko was recorded between 1961 and 1970 (Serafimov 1978) before the site was upgraded (*table 7*). Other climate stations in the study area include: Dolna Bania (42° 18′ N, 23° 45′ E; 635m); Samokov (42° 19′ N, 23° 34′ E; 1,030m); Borovets (42 ° 15′ N, 23 ° 37′ E; 1346m); Sitniakovo (42° 14′ N, 23° 37′ E; 1,742m); Yazavor Beli Iskar (42° 09′ N, 23° 16′ E; 2390m); Hija Musala (42° 12′ N, 23° 26′ E; 2,392m); and Vrah Musala (42° 11′ N, 23° 35′ E; 2,925m).

Table 7 — *Ovnarsko no. 3 Climatology, 1961-1970.*

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2m temperatures within stand (°C)	- 5.4	- 3.4	- 1.4	3.1	8.2	11.7	13.5	13.1	9.9	5.6	2.7	- 2.2
2m temperature in open (°C)	- 4.9	- 2.8	- 0.6	4.4	9.5	13.0	14.8	14.1	10.4	6.1	3.2	- 2.0
2m max temperature within stand (°C)	- 1.7	0.4	1.8	6.9	12.2	15.3	17.4	17.3	14.1	9.6	5.6	0.8
2m max temperatures in open (°C)	- 0.2	2.7	3.6	9.1	13.9	16.8	18.9	19.3	16.2	11.8	7.4	2.5
2m min temperature within stand(°C)	- 8.0	- 6.3	- 4.2	- 0.1	4.1	7.2	8.7	8.6	6.4	2.6	-0.5	- 6.0
2m min temperature in open (°C)	- 8.7	- 7.5	- 4.6	- 0.5	3.9	6.9	8.2	8.2	5.7	2.0	- 0.9	- 5.6
2m wind speed stand (m s^{-1})	0.25	0.31	0.25	0.28	0.17	0.16	0.16	0.16	0.20	0.26	0.25	0.28
2m wind speed open (m s^{-1})	0.73	0.85	0.77	0.81	0.59	0.53	0.53	0.55	0.69	0.79	0.90	0.91
Precipitation (mm)	71	61	66	82	106	120	90	63	57	69	72	70
2m RH in stand (pct)	86	83	82	78	77	79	76	75	76	75	79	85
2m RH in open (pct)	84	81	79	72	72	73	70	71	73	72	76	84

Precipitation chemistry was sampled in 1989 and pH was below 4.5 (*table 8*). Because there were no nearby sources causing low pH precipitation and an exact record does not exist, it was expected that the Govedartsi valley should be clean of air pollutants. The low pH measurements (*table 8*) were a surprise at the time (Serafimov 1978) and remain unexplained. The concentrations of nitrates are low. Concentrations of chlorides and sulfates and concentrations of heavy metals are indicative of those naturally occurring.

Table 8 — *Precipitation chemistry composition of 1989 samples with < 4.5 pH.*

Ion	NO_x	Cl	SO_x	Pb	Cu	Mn	Ni	Cd
mg L^{-1} (FAO 1989)	0.58	0.44	1.4	11.5	1.6	12.5	2.0	0.8

Sulfate (SO_4^{2-}) and Nitrate (NO_3^-) Concentrations and Deposition

A total of 15, multi-day filter pack samples exposed during summer and autumn periods between May 6, 1992 to November 6, 1993 were recorded (*table 9*). The three initial samples taken between the period September 11, 1991 to October 27, 1991, as reported by Zeller and others (1992) were atypical and not repeated here. Deposition in kilograms per hectare per year (kg ha^{-1} yr^{-1}) was calculated by assuming 0.4 cm s^{-1} deposition velocity (Bytnerowicz and others 1987). If the 1992 and 1993 data are extrapolated for an entire year, NO_3^- deposition would be 1.3 and 0.3 kg ha^{-1} yr^{-1} respectively. Deposition for SO_4^{2-} would be 3.6 and 3.3 kg ha^{-1} yr^{-1} respectively. These last deposition estimates give an indication of annual values only and should be used with caution because measurements were never taken for the entire year, nor were any measurements taken during winter and spring seasons.

Sulfate concentrations are similar to those found in other parts of Europe (Ruijrok and others 1995) but below those in more polluted regions (Zeller and others 1996). The projected annual SO_4^{2-} aerosol deposition is similar to results for higher polluted regions (Zeller and others 1996), where deposition velocities were individually modelled and typically below 0.4 cm s^{-1}, which might explain the comparison difference between concentration and deposition results. Nitrate concentration and deposition at Ovnarsko are lower than those found in more polluted regions.

***Table 9** — Filter pack concentrations and calculated deposition.*[1]

Days exposed	Date On	Concentration ($\mu g\ m^{-3}$) NO_3^-	SO_4^{2-}	Deposition kg ha^{-1} yr^{-1} NO_3^-	SO_4^{2-}
32	05/06/92	0.17	4.30	0.21	5.42
8	06/06/92	0.26	2.03	0.33	2.56
7	06/14/92	0.38	2.17	0.48	2.74
7	06/21/92	0.27	1.48	0.34	1.87
7	06/28/92	0.18	1.80	0.23	2.27
7	07/05/92	4.89	5.20	6.17	6.56
16	06/13/93	0.39	4.19	0.49	5.29
17	06/29/93	0.59	5.25	0.74	6.62
20	07/16/93	0.14	2.13	0.17	2.69
17	08/05/93	0.20	1.31	0.25	1.65
17	08/22/93	0.17	1.17	0.21	1.48
17	09/08/93	0.22	3.09	0.27	3.90
15	09/25/93	0.14	1.78	0.17	2.25
13	10/10/93	0.16	2.38	0.20	3.00
14	10/23/93	0.22	2.29	0.27	2.89

[1] 0.4 cm s^{-1} deposition velocity.

Conclusion

The cooperative Bulgarian Rila Mountain forest ecosystems study site, Ovnarsko no. 3, has been described with initial dry deposition results. Although data were not collected for the winter and spring seasons, results indicate SO_4^{2-} and NO_3^- aerosol concentrations are similar to other less polluted regions of Europe, while deposition of NO_3^- is also low and deposition of SO_4^{2-} may be similar to higher polluted areas. This result is dependent on modelled deposition velocity and needs further study.

Acknowledgments

We are grateful for the following support: Al Reibau, Lucenda Smith and Michael Sestak NBS/ESTC, Fort Collins, Colorado for providing the filter pack pump system; the USDA Office of International Cooperation and Development for initial site survey funds; Mr. Spas Ashkov and staff, FRI Ovnarsko station, Govedartsi for local site support, and Danko, Ltd. for electronic support. We also thank Laurie Dunn for technical editing of this manuscript.

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