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THE EFFECTS OF DISTURBANCE EVENTS ON THE SUBMERGED BRYOPHYTE VEGETATION IN THE STREAMS OF THE TATRA MOUNTAINS SLOVAKIA

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Abstract

Submerged bryophytes are often important constituents of stream vegetation. Almost the whole area of the Tatra mountains (The West Carpathians, 28 streams) has been surveyed by a large number of sampling sites (78) at altitudes between 639 - 2002 m a.s.l. The lower parts of the streams are mostly the areas with disturbance events - roads, clearings, built up areas, avalanche sites, bark beetles infection, wind-thrown trees and ski resorts. Conductivity, pH, dissolved oxygen, redox potential, chemical oxygen demand, calcium carbonate, nitrates, ammonia and chlorides were plotted as ordination axes, for their ecological interpretation, disturbance events were plotted onto CCA ordination diagram. Only bryophytes recorded ≥3 times in the streams have been submitted to ordination analyses: *Scapania undulata* (L.) Dumort., *Brachythecium rivulare* B. S. G., *Fontinalis antipyretica* Hedw., *Hygrohypnum luridum* (Hedw.) Jenn., *Hygrohypnum ochraceum* (Wilson) Loeske, *Palustriella commutata* (Hedw.) Ochyra and *Platyhypnidium riparioides* (Hedw.) Bruch & Schimp. Correlation between disturbance events and bryophytes was seen, shown by Canonical Correspondence Analysis CCA. In the term of heavy metal accumulation, the aquatic bryoflora is relatively well investigated, this is not true in terms of nutrient preferences or tolerances. This is why we have decided to fill this knowledge gap. We have found, that natural and anthropogenic disturbance events result in extra input of nutrients.

Introduction

The Tatra Mountains are located at the Northern, highest area of the Carpathian mountain range (Central Europe), along the Polish-Slovakian border. On November 19, 2004, the Northern down-slope wind (locally named Bora) felled 12,000 ha of forest; about 2.3 million m^3 of wood in the Tatra Mts. This event was followed by a severe fire in 2005. Forest stand disintegration or deforestration may cause disturbance of the biogeochemical cycles in terrestrial or aquatic ecosystems and may disturb hydrology and ecology (Růžičková *et al*., 2001) . Aquatic bryophyte species are often a conspicuous elements of the macrophyte vegetation of streams and lakes. Water quality changes from precipitation with minerals almost absent, to calcium-enriched water, cause a differentiation in macrophyte communities (Barendregt, 2003). In extreme habitats, where angiosperms cannot survive, bryophytes may be abundant.

Submerged bryophytes have often been the matter of interest of more botanisis, e. g. Englund *et al*., (1997), Bleuel *et al*., (2005), Hongve *et al*., (2004), Martins *et al*., (2004), Rau *et al*., (2007), Fritz *et al*., (2009), Thiebaut *et al*., (1998). Human impact to riparian bryophytes was studied by Luis *et al*., (2010). They investigated 16 streams over the northern and southern slopes of Madeira and found, that human impact probably contributed to the lower species diversity. In the Tatra Mts, the water quality investigation has been focused mainly on the still waters in the Tatra lakes (Fott *et al*., 1994; Kopáček & Stuchlík, 1994). In the running water, Samecka-Cymerman *et al*., (2007) used the aquatic bryophytes as bioindicators to determine metal levels in the streams of The Tatra Mountains.

In the terms of bryophytes nutrient preferences or tolerances refering to small streams, the state of our knowledge is rather poor. Schneider *et al*., (2000) studied macrophyte vegetation and the epilithic diatoms, nutrients and the physicochemical characteristics in a small oligotrophic stream in Germany. Małek & Krakowian (2009) analysed waters in the catchments of 2 streams in the Beskid Śląski.

The following questions are addressed in this paper:

1. How is bryophyte species composition in the Tatra Mts streams related to physico-chemical factors, i. e. conductivity, pH, redox potential, chemical oxygen demand, dissolved oxygen, chlorides, amonia, nitrates, $CaCO_3$.
2. How many bryophytes are tied to the disturbance events along streams and how are bryophyte habitats conditioned by windthrows, bark beetles infection, avalanche areas, roads, clearings, built up areas, ski resorts.

Material and methods

Study sites and sampling: 28 streams in the Tatra Mts. were selected (Table 1). For each stream, 4-5 sampling sites were selected along an altitudinal gradient from montane up to alpine regions. The sampling sites with < 3 bryophytes species occuring were excluded from ordination analyses. Thus, the whole dataset contains records from 78 sampling sites at altitudes between 639-2002 m a.s.l., including 60 sampling sites in disturbanced areas - roads, clearings, built up areas, avalanche sites, bark beetles infection, wind-thrown trees and ski resorts. The plots were sampled once between June- October 2010. Every sampling site has been fixed by GPS.

Data analysis: To explain the effects of disturbance events on the submerged bryophyte vegetation, we used ordinations constrained by explanatory variables. The data matrix (species–environmental variables) consists of data from 78 sites. Since the length of the first gradient in the log report was 3.5, we used the unimodal methods-CCA (Ter Braak & Šmilauer, 2002). The following variables were used as ordination axes: chemical oxygen demand (COD), dissolved oxygen, reduction potential (ORP), conductivity, pH, $CaCO_3$, NH_4^+, NO_3^- and Cl^-. CANOCO 4.5 for Windows package (Ter Braak & Šmilauer, 2002) was used for statistical analysis.

Table 1. 78 sampling sites, list of geographical data.

Sampling site	Coordinates	Altitude [m a.s.l.]	Bryophytes	Sampling site	Coordinates	Altitude [m a.s.l.]	Bryophytes
BIE2	N 49°15,539' E 020°12,770'	1128	Palcom	SMR1	N 49°11,350' E 019°44,493'	1631	Palcom
BIE3	N 49°16,071' E 020°13,215'	988	Brariv	SMR2	N 49°10,844' E 019°43,182'	1270	Brariv
JAV3	N 49°12,297' E 020°09,451'	1514	Brariv	SMR3	N 49°10,380' E 019°42,836'	1165	Brariv
JAV5	N 49°15,228' E 020°09,143'	1059	Brariv, Hyglur	SMR4	N 49°08,703' E 019°42,003'	901	Brariv
BIVO2	N 49°11,082' E 020°06,877'	1397	Scaund	JAL1	N 49°11,583' E 019°41,672'	1431	Palcom
KBV2	N 49°12,651' E 020°13,436'	1529	Fonant	JAL2	N 49°11,377' E 019°40,332'	1142	Brariv
KBV3	N 49°12,900' E 020°15,276'	1305	Fonant	JAL3	N 49°11,296' E 019°39,737'	1048	Hyglur
KBV4	N 49°11,678' E 020°16,833'	1010	Hyglur	JAL4	N 49°09,844' E 019°38,854'	862	Brariv
SKA2	N 49°11,046' E 020°14,902'	1331	Hyglur, Scaund	KAM1	N 49°11,419' E 019°51,600'	1633	Scaund
SKA3	N 49°11,085' E 020°15,686'	1135	Hyglur, Hygoch	KAM2	N 49°11,053' E 019°51,646'	1497	Palcom
MSTU1	N 49°11,441' E 020°11,963'	2002	Scaund	KAM3	N 49°10,149' E 019°52,584'	1273	Brariv
MSTU2	N 49°11,114' E 020°12,369'	1939	Hygoch	KAM4	N 49°08,173' E 019°53,790'	910	Palcom
MSTU4	N 49°10,171' E 020°13,069'	1311	Scaund	BYS1	N 49°10,497' E 019°50,778'	1774	Palcom
VSTU1	N 49°10,629' E 020°10,682'	1746	Scaund	BYS2	N 49°10,020' E 019°50,958'	1547	Palcom
VSTU2	N 49°10,593' E 020°11,138'	1603	Scaund	BYS3	N 49°09,210' E 019°51,136'	1264	Brariv
SLA1	N 49°08,508' E 020°11,056'	1252	Hygoch	RAC1	N 49°11,574' E 019°48,748'	1648	Brariv
SLA2	N 49°07,911' E 020°11,855'	1028	Hygoch	RAC3	N 49°09,725' E 019°48,479'	1142	Hyglur
SLA3	N 49°07,756' E 020°12,129'	973	Fonant	RAC4	N 49°08,836' E 019°47,673'	949	Hygoch
VEL3	N 49°08,730' E 020°10,117'	1461	Scaund	RAC5	N 49°06,304' E 019°48,482'	791	Palcom
VEL4	N 49°07,273' E 020°10,468'	990	Brariv	JAM1	N 49°11,925' E 019°46,512'	1654	Palcom
BAT2	N 49°08,167' E 020°07,934'	1401	Hyglur	JAM2	N 49°11,506' E 019°46,561'	1376	Scaund, Fonant

Table 1. (Cont'd.).

Sampling site	Coordinates	Altitude [m a.s.l.]	Bryophytes	Sampling site	Coordinates	Altitude [m a.s.l.]	Bryophytes
BAT3	N 49°07,495' E 020°08,326'	1130	Scaund	JAM3	N 49°10,583' E 019°43,432'	1168	Rhyrip
VSUM1	N 49°08,160' E 020°05,893'	1481	Hygoch	BOB1	N 49°14,764' E 019°46,079'	1178	Brariv
VSUM2	N 49°07,529' E 020°06,447'	1191	Hygoch	BOB2	N 49°15,544' E 019°45,428'	1010	Hyglur
POP1	N 49°08,928' E 020°04,719'	1464	Scaund	ROH1	N 49°12,759' E 019°44,849'	1382	Palcom
POP3	N 49°07,864' E 020°04,466'	1267	Scaund	ROH2	N 49°13,296' E 019°43,647'	1204	Hygoch
POP4	N 49°06,983' E 020°04,943'	1195	Scaund	ROH3	N 49°14,176' E 019°42,925'	1080	Hygoch
POP5	N 49°05,015' E 020°08,543'	816	Fonant	ROH4	N 49°14,311' E 019°42,973'	1066	Scaund
MLY1	N 49°09,605' E 020°02,520'	1892	Scaund	LAT1	N 49°13,781' E 019°45,391'	1336	Palcom
MLY2	N 49°09,090' E 020°02,828'	1685	Scaund	LAT2	N 49°14,549' E 019°42,934'	1076	Rhyrip
MLY3	N 49°08,330' E 020°03,158'	1488	Scaund	LAT3	N 49°14,558' E 019°42,898'	1075	Rhyrip
MLY5	N 49°04,366' E 020°04,591'	859	Fonant, Hygoch	STU	N 49°14,725' E 019°42,466'	1024	Fonant, Hygoch
BVA1	N 49°09,105' E 020°00,238'	1836	Scaund	TICH1	N 49°12,724' E 019°59,187'	1532	Scaund
BVA2	N 49°08,162' E 020°00,981'	1451	Scaund	TICH2	N 49°13,049' E 019°58,700'	1369	Scaund
BVA4	N 49°03,460' E 019°58,319'	783	Brariv	TICH3	N 49°13,327' E 019°57,556'	1252	Palcom
BEL1	N 49°08,478' E 019°58,901'	1295	Brariv	TICH4	N 49°4,549' E 019°42,934'	986	Palcom
SUCH1	N 49°12,777' E 019°36,441'	1030	Palcom	KOP1	N 49°11,631' E 020°00,997'	1495	Scaund
SUCH2	N 49°12,106' E 019°35,816'	901	Palcom	KOP2	N 49°11,222' E 019°59,443'	1333	Palcom
SUCH3	N 49°10,339' E 019°34,730'	735	Palcom	KOP3	N 49°09,426' E 019°57,974'	1194	Scaund

List of sampling sites: BIE - Biela; JAV-Javorinka; BIVO-Biela voda; KBV-Kežmarská biela voda; SKA-Skalnatý potok; MSTU-Malý Studený potok (The High Tatra Mts); VSTU-Veľký Studený potok (The High Tatra Mts); SLA-Slavkovský potok; VEL-Velický potok; BAT-Batizovský potok; VSUM-Veľký Šum; POP-Poprad; MLY-Mlynica; BVA-Biely Váh; BEL-Beliansky potok; SUCH-Suchý potok; SMR-Smrečianka; JAL-Jalovský potok; KAM-Kamenistý potok; BYS-Bystrá; RAC-Račkov potok; JAM-Jamnický potok; BOB-Bobrovecký potok; ROH-Roháčsky potok; LAT-Látaná; STU-Studený potok (The West Tatra Mts); TICH- Tichý potok; KOP-Kôprovský potok

Species list: Brariv-*Brachythecium rivulare*, Hyglur-*Hygrohypnum luridum*, Palcom-*Palustriella commutata*, Scaund-*Scapania undulata*, Fonant-*Fontinalis antipyretica*, Hygoch - *Hygrohypnum ochraceum*, Plarip-*Platyhypnidium riparioides*.

For ecological interpretation of the ordination axes, disturbance events (roads, clearings, built up areas, avalanche sites, bark beetles infection, wind-thrown trees and ski resorts) were plotted onto CCA ordination diagram as supplementary environmental variables.

The statistical significance of the explanatory (environmental) variables in the canonical method were determined by Monte Carlo permutation tests. Explanatory variables were tested separately (partial tests). Because of the discontinuity and the heterogeneity of aquatic bryophytic habitats, presence of species was preferred to estimation of abundance.

Chemistry: The following parameters were measured by portable devices at sampling sites: Conductivity using device YSI EC300. pH is measured using device YSI pH100. Determination of dissolved oxygen is based on fluorescence detection using device YSI DO200. Determination of chlorides, amonia and nitrates is based on colorimetry using direct-reading photometer YSI 9500. Redox potential (ORP) using device YSI ORP 15. Volumetric methods have been used for determination following features-manganometry for chemical oxygen demand (COD) determination and chelatometry for $CaCO_3$ determination.

Results and Discussion

The following submerged bryophytes were recorded ≥ 3 times in the streams: *Scapania undulata* (23 times), *Brachythecium rivulare* (15 times), *Fontinalis antipyretica* (7 times), *Hygrohypnum luridum* (8 times), *Hygrohypnum ochraceum* (12 times), *Palustriella commutata* (18 times), *Platyhypnidium riparioides* (3 times). *Chiloscyphus polyanthos* (L.) Corda, *Cratoneuron filicinum* (Hedw.) Spruce, *Hydrogrimmia mollis* (B. S. G.) Loeske, *Hygrohypnum duriusculum* (De Not.) D. W. Jamieson, *Pohlia drummondii* (Müll. Hal.) A. L. Andrews and *Racomitrium aquaticum* (Schrad.) Brid., were recorded also, but because of rare occurence (<3 x), these were excluded from ordination. The bryophytes identified are given in Table 1.

Mean and mode values as well as the ranges of environmental variables are given in Table 2. Ammonia content of the 78 sites within 28 sampled streams was low, ranged between 0 and 0.37 mg $NH_4^+.L^{-1}$ (Mode 0.04); conductivity ranged in large extent from 5.3 µS cm^{-1} at headwater areas to 282.6 µS cm^{-1} at areas with different human interactions (at 20 °C) (Mode 31.8). pH varied from 6.16 to 8.54 (Mode 7.42), concentrations of major anions ranged between 0 and 4.7 mg $.L^{-1}$ (Mode 0.40 mg. L^{-1}) for Cl^-, between 0.421 and 4.335 mg $.L^{-1}$ for NO_3^- (Mode 1.37 mg. L^{-1}). ORP (oxidation - reduction potential) and COD (chemical oxygen demand) of the streams varied from 101 to 373 mV (Mode 229) and from 0.080 to 4.507mg.l^{-1} (Mode 1.04mg oxygen. L^{-1}), respectively. ORP sensor allow us electronically monitor sanitizer residual. Ca^{2+} is usually a dominant cation, concentration of $CaCO_3$ ranged between 3.34 and 179.66 mg. L^{-1} (Mode 18.52). Dissolved oxygen varied in the range 5.9-16.46 mg. L^{-1} (Mode 12.36 mg. L^{-1}).

Table 2. Minimum, maximum, mean and mode values of major ions, nutrients and physical features in 28 Tatra Mts streams (78 sampling sites).

	Minimum	Maximum	Mean	Mode
$CaCO_3$ (mg.L^{-1})	3.34	179,66	24,66	18.52
Cl^- (mg.L^{-1})	0.0	4.7	0.46	0.40
NO_3^- (mg.L^{-1})	0.42	4.34	1.16	1.37
NH_4^+ (mg.L^{-1})	0.00	0.37	0.03	0.04
Dissolved O_2 (mg.L^{-1})	5.90	16.46	12.11	12.36
Conductivity (µS)	5.3	282.6	36.6	31.8
pH	6.16	8.54	7.24	7.42
ORP (mV)	101	373	265	229
COD (mg oxygen.L^{-1})	0.080	4.507	1.285	1.040

The first axis shows 36.5% relationship between the bryophytes and the chemical variables, this axis highly correlates with $CaCO_3$ and conductivity, and to a lesser extent with pH (Fig. 1). The first axis shows 6.8% of the variance of the bryophytes. The second axis shows 30% relationship between the bryophytes and the physicochemical variables, these axes correlates with NO_3^-, Cl^-, dissolved oxygen, COD and pH. Built up areas and windthrows areas are habitats correlated with these trends. This axis explains 5.7% of the variance of the bryophytes.

Conductivity and $CaCO_3$ content are positively correlated (r = 0.98), also positively correlated are conductivity and pH level (r = 0.75), $CaCO_3$ content and pH level (r = 0.79). Cl^- content is positively correlated with COD (r = 0.63) and with NO_3^- (r = 0.77). Dissolved oxygen is negatively correlated with reduction potential (ORP) (r = -0.74) as well as altitude to pH level (r = -0.59). (Altitude p = 0.002, F = 3.577; pH p = 0.002, F = 3.359; conductivity p = 0.012, F = 2.918; $CaCO_3$ p = 0.020, F = 2.747; COD p = 0.156, F = 1.470; dissolved oxygen p = 0.080, F = 1.798; NO_3^- p = 0.164, F = 1.508; redox potential (ORP) p = 0.156, F = 1.561; Cl^- p = 0.278, F = 1.261; NH_4^+ p = 0.522, F = 0.802).

Correlations between calcium carbonate and conductivity or between conductivity and pH level are easy to explain. The more calcium cations, the higher conductivity and the more basic reaction. Correlation between chlorides and nitrates is also explicable, they have partly common origin. In mountain conditions, chlorides concentration in running waters depends exclusively on atmosphaeric precipitation. Nitrates source are atmosphaeric deposition and decomposition of organic substances in soils. Negative correlation between dissolved oxygen and oxydo-reduction potential is unexpected and difficult to explain. The value of redox potential gives information on oxidative or reducing conditions in the waters. Positive value indicates oxidative situation in the waters and negative value indicates reducing status. In natural waters oxidative situations are connected with dissolved oxygen, thus positive correlation is expected. Dissolved oxygen is the most important disolved gas and is requirement for life in waters. In running waters predominates oxygen of atmospheric origin and is indicator of water purity. Total dissolved oxygen concentrations in water should not exceed 110 percent. Concentrations above this level can be harmful to aquatic life, such concentrations we have recorded in streams running through built-up areas.

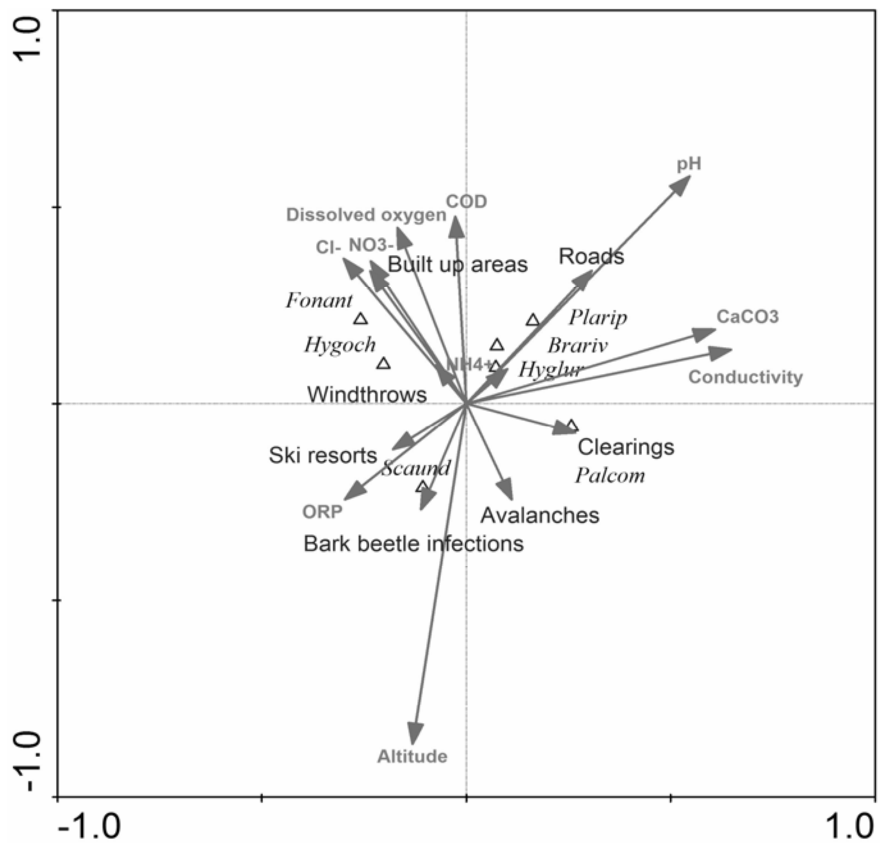

Fig. 1. Triplot, canonical correspondence analysis (CCA), the relationship of environmental variables and submerged bryophytes in streams. Species list: Brariv-*Brachythecium rivulare*, Hyglur-*Hygrohypnum luridum*, Palcom-*Palustriella commutata*, Scaund-*Scapania undulata*, Fonant-*Fontinalis antipyretica*, Hygoch-*Hygrohypnum ochraceum*, Plarip-*Platyhypnidium riparioides*.

The pH-value shows a distinct increase downstream from 6.42 to 8.44, along with a slight increase of conductivity. Bryophytes that correlate to a pH shift to neutral or basic are *Brachythecium rivulare, Hygrohypnum luridum* and *Platyhypnidium riparioides.* Infrastructures, such as roads, are correlated with this trend. Nitrates, chlorides, dissolved oxygen, and chemical oxygen demand (COD), are also relevant indicators of water quality, with the associated bryophytes of *Fontinalis antipyretica* and *Hygrohypnum ochraceum.* At headwater areas the chemistry of the waters is comparable to precipitation. The lower parts of the streams between altitudes 700-1200 m a.s.l. are mostly the areas with windthrows, forest stands infected by bark beetle or different human interactions (roads, tourist paths, ski resorts, built up areas). The nitrate concentrations are also markedly increasing downstream from 0.5 to more than 4.0 mg $NO_3^-.l^{-1}$. Built up areas and windthrows are associated with these trends. *Palustriella commutata* prefers clearings and avalanche areas. *Scapania undulata* is the most frequently occurring species, correlating with altitude. Ammonia concentrations stay at a low level (Table 2).

The presence of bryophyte species is influenced by a number of factors from other processes associated with eutrophication. Crowded sites like roads, built up areas, ski resorts are potential sources of nutrients, where a rapid leaching of salts from surface layers happen (Quamar *et al*., 2011). Similar source of nutrients identified Schneider *et al*., (2000) in Germany, near a small calcareous stream Lauterbach. Ammonia, pH, nitrate, oxygen, conductivity and others parameters were determined and adjacent golf course was identified as a possible source of nutrients. The increase in major ion concentrations due to human impact is often indicated by an increased electric conductivity of the water. The composition of riparian tree species or their absence in disturbed sites affects the microclimate and therefore the vegetation pattern. Different tree species also affect the supply of nutrients in the rainwater by substances released from leaves (Darell & Cronberg, 2011). The roots of irrigated plants are more affected than shoots (Yasmin *et a*l., 2011).

Natural disturbances (windthrow, bark beetles infection, avalanche areas) and anthropogenic disturbance events (roads, clearings, built up areas, ski resorts) resulting in extra input of nutrients. The actual nutrient site conditions affect bryophyte distribution, and here, the availability of nutrients determines growth.

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