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The Effect of Stemflow on Transplanted *Hypogymnia physodes* in the Urban Area of Salzburg (Austria)

By

R. TÜRK[1] & C. MOSER[1]

Key words: Lichen, stemflow, air pollution, raintracks, CO_2 exchange, chlorophyll content, urban area of Salzburg.

Summary

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In the city of Salzburg a study was carried out to investigate possible effects of the stemflow on lichens using a transplant technique along raintracks of trees. Between November 2000 and June 2001 specimens of *Hypogymnia physodes* were exposed around the trunks of *Tilia cordata* at 6 different sites in the urban area of Salzburg. The lichen thalli were fixed on discs of cork which were fitted into bark holes. As the physiological response of the exposed lichens the CO_2-gas exchange was observed in time intervals of 4 weeks. Also the pigment content was measured after exposition. Visible damage and changes in the size of the exposed lichen samples were determined photographically. The stemflow after a rain phase was collected with an equipment created by the department of environmental protection of the provincial government of Salzburg and analysed for conductivity, pH and the content of Ca^{2+}, SO_4^{2-}, NH_4^+, NO_3^- and Zn.

After 6 months of exposure most of the specimens showed no seriously visible damages. Only some peripheral and selective chlorosis and necrosis appeared. At several sites growth of the thalli was observed to a certain extent.

The lichens had unimodal responses in gas exchange. The physiological activity varied with alteration in environmental conditions. After rain periods the NP-rates were increasing and the DR-rates were significantly negative correlated.

The lichens had unimodal responses in gas exchange. The physiological activity varied with alteration in climatic conditions. After rain periods the NP-rates were increasing and the DR-rates were significant negative correlated.

No apparent changes in chlorophyll a and b content occured.

Average levels of contaminants were low but showed higher values in the winter months.

[1] Universität Salzburg, Fachbereich Organismische Biologie, Hellbrunnerstr. 34, 5020 Salzburg, Austria, e-mail: roman.tuerk@sbg.ac.at

Abbreviations: NP: net photosynthesis, DR: dark respiration, Chl: chlorophyll, Phae: phaeophytin, TA: thallus area, DW: dry weight, PPFD: photosynthetic photon flux density, SA: stemflow.

Introduction

Epiphytic lichens are among the best known and extensively used bioindicators of air pollution studies (FERRY & al. 1973, NASH & WIRTH 1988, WERNER 1993, TÜRK & CHRIST 1980, VAN DOBBEN & BRAAK 1999). This is due to physiological properties of the lichen thallus: its slow growth and its effectiveness in absorbing soluble and insoluble mineral nutrients from ambient air and precipitation with little subsequent loss (BRUTEIG 1993).

The greater sensitivity of epiphytic lichens to air pollution in comparison with higher plants can be attributed to their primitive structure, their adaptation to epiphytic life and their longevity and associated physiological activity in the cooler and moister winter part of the year with a high air pollution load (FERRY & al. 1973, NASH & WIRTH 1988, TÜRK 1991).

Often before visible damages occur, physiological parameters like photosynthesis, respiration and growth are reduced (BEEKLEY & HOFFMANN 1981). In numerous studies changes in photosynthetic rates of lichens were used to measure their response to various pollutants (CHRIST & TÜRK 1981, NASH & WIRTH 1988).

The transplantation method developed by BRODO 1961 using bark-discs bearing epiphytic lichens and mosses which are placed onto trees at selected sites in a polluted area, has been satisfactorialy used by ecologists to assess the effects of pollution on these organisms (BRODO 1966, LE BLANC & RAO 1966, WERNER 1993, HUFNAGEL & TÜRK 1998).

The main sources of nitrogen and sulphur for lichens are atmospheric inputs as rain, horizontal interception and dust. Contributions from stemflow and canopy leachates also favour accumulation of elements in corticolous species (BRUTEIG 1993). An uptake of leachate from stemflow by epiphytes was demonstrated in numerous studies (SLACK 1988). Epiphytic lichens contain a pool of stored minerals in all ecosystems in which they occur (PIKE 1978).

The main objective of this study was to use the epiphytic lichen *Hypogymnia physodes* (L.) NYL.) to assess the effect of the stemflow of trees, that conducts the polluted rainwater from the top to the soil, on the physiology of lichens along raintracks. Healthy thalli from a slightly polluted, rural area were transplanted around the tree trunks of Tilia sp. at 6 sites in the area of Salzburg. During 6 months of exposure it was investigated whether the vitality of epiphytic lichens along the raintracks changed in time. Also visible damages like chlorosis or necrosis were observed. The response variables used to measure metabolic disturbance include inhibition of photosynthetic fixation, changes in respiration rates and chlorophyll degradation.

In addition, it was investigated if there is any difference between the specimens which have been exposed directly along the raintracks and others which have been situated at the opposite exposition. HERZIG & URECH 1991 found significant distinctions in various element contents in thalli of *Hypogymnia physodes* on different expositions in dependence on air freight as well as the raintracks.

To analyze the ingredients of the stemflow, a special apparatus was developed and installed on the tree trunks to collect the diverted rainwater. The results of these measurements should be related with the physiological parameters and with the alteration of atmospheric deposition and climatic data.

Material and Methods

The epiphytic lichen *Hypogymnia physodes* (L.) Nyl. was used as monitoring organism, because it is a foliose lichen and can be separated from the bark substratum, and it is enough tolerant to pollution (OKSANEN & al. 1991). It is a common circumpolar species and has proved to be suitable for investigation of local pollution (PFEIFFER & BARCLAY-ESTRUP 1992, GUDERIAN & al. 1985, WERNER 1993, EGGER & al. 1994, HUFNAGEL & TÜRK 1998). The sensibility against immissions of this lichen is high enough and since a long time it is successfully used in transplantation experiments.

Hypogymnia physodes is a moderate acid- and toxitolerant species (HERZIG & URECH 1991).

The lichen thalli for the study were collected in February 2000 in Lauda-Königshofen „Burgladen“ in the area of Taubertal, Baden Württemberg, Germany at an elevation of about 310 msm. This valley was chosen, because it is considered to be only a slightly polluted area with a high diversity of epiphytic lichens. The thalli were collected from the bark of apple-tree (*Malus domestica*).

Because younger and older thallus fragments are different in their physiological response and younger thalli are more sensitive to noxious immissions it was important to take thalli which are more or less of the same size and age. All thalli were transported air-dried to the University of Salzburg and kept frozen in the dark at -18 °C. At this storage temperature the photosynthetic efficiency is maintained unlimited (LANGE 1966, HUFNAGEL & TÜRK 1998).

The lichens were carefully cleaned from adhering substrate rests. Then they were stored in the air dried state in the dark at -18 °C. The lichen samples were fixed with a fishing line and pinboard nails on discs of untreated cork with a diameter of about 40 mm and a thickness of 5 to 7 mm according to WERNER 1993.

Six lime-trees (*Tilia cordata* Miller and *T. platyphyllos* Scop.) at different sites in the area of Salzburg were chosen for the transplantation. The trees were exposed to more or less similar conditions of light, temperature and humidity and showed no natural cover of *Hypogymnia physodes*.

The exposure sites were Hellbrunnerstraße (location A, 430 m), Minnesheim-Park (location B, 430 m), Bürglstein (location C, 450 m), Kapuzinerberg (location D, 575 m), Gaisberg (location E, 980 m) and Mönchsberg (location F, 470 m).

At each site 10 thalli were transplanted around the trunk at a height of about 2 meters from the base. An about 10 mm deep hole with a diameter of 40 mm was knocked out of the bark using a punch. The cork discs then were fitted into the holes and fixed with the pinboard nails so that the lichens were on a level with the bark.

Visible changes

To document visible changes of the transplanted lichens, every months each thallus was moistened with deionized water and photographed with a color film in artificial light. The slides were scanned by an EPSON Perfection 1240U into the Program Adobe Photoshop, where the photographs of each thallus were distinguished and the visible changes in time of each explant could be analysed.

The extent of damage caused to the epiphytes was assessed subjectively by noting the changes in their coloration and by estimating the proportion of apparently dead plant cover (LEBLANC & RAO 1973).

To determine possible changes in the thallus size an initial and final counting of the area was carried out and related to each other.

CO_2-exchange

Every 4 weeks 6 lichen specimens of each tree (3 from the rain-tracks and 3 from the opposite expositions) were removed and the CO_2 exchange of the whole thalli was measured under controlled conditions by means of a compact minicuvette system (CMS-400, Walz, FRG) in the open flow system in the laboratory. The BINOS 100 4p infrared gas analyser (Rosemount, FRG) registrated NP and DR with an accuracity of ± 0.1 ppm at decreasing WC. DR was measured with the cuvette blacked out by a cover. The measurements were carried out at a photosynthetic photon flux density (PPFD) of 800 µmol $m^{-2}.s^{-1}$, a temperature of 15 °C and relative humidity of approximately 70 %. The CO_2 concentration ranged between 360 and 390 ppm. Fresh weight was measured after the measurement. Actual water content (WC) was detected gravimetrically with an electronic balance (SBC-41, Scaltec Instruments, FRG). To obtain water saturation of the thalli, the lichens were submersed for 10 minutes in deionized water before every measurement. Adhering water droplets were removed by shaking the thalli.

The maximal NP-rates at optimal water content (ranging between 55 - 75 %) were mostly achieved at the first light periode, which lasted no more than 10 min. The lichens were desiccated very fast and the photosynthesis became moderately depressed.

The CO_2 exchange rates are expressed on a surface-area basis (as µmol CO_2 $m^{-2}.s^{-1}$) using a mean thallus surface area of 5 measurements carried out with a LI-3000 A Portable Area Meter (LI-COR, Inc).

After these measurements the thalli were fixed again on the bark discs and brought back to the place of exposure on the trees.

Chlorophyll content

After 6 months of exposure the chlorophyll content of 4 specimens per tree was determined by extraction with acetone according to BROWN & HOOKER 1977. The chlorophyll content was then expressed on a weight basis (mg Chl g^{-1} dry weight). Thallus dry weight was determined after 24 hours at 105 °C. The relation between Chl a and Phae a was determined as follows: Rt-value = E 663 / E 534. Before the exposition process the pigment contents of 10 specimens of the fresh collected lichen material were measured as the reference value of the chlorophyll content and the mean value was calculated.

Deposition and climatic data

Deposition and climatic data in the exposition period were provided by the provincial government of Salzburg, department of immission protection, which maintains a record of the emissions in the area.

The most important air pollutants are monitored continuously at certain measuring sites throughout the Salzburg region. For the present study the parameters NO_X, CO, SO_2, NO_2, NO, dust and temperature at station Rudolfsplatz, ozone at station Mirabellplatz as well as precipitation from the weatherservice station were taken into account. The data were related to the exposure periods on the particular sites.

The stemflow solution was collected directly with a special apparatus developed and installed by the provincial government of Salzburg. A plastic vessel for 1 litre liquid was fixed on the trunks and with a special rubber band around the trunk the drain was collected. A sponge within the vessel prevents an overflow of the solution which was than analyzed at the regional laboratory of the government for different parameters such as pH-value, electric conductivity, their levels of ammonium, nitrate, sulphate, calcium, potassium, zinc, Mg, Na and Al.

Data analysis was conducted by using Excel 2000 and SPSS statistical programs.

Results

Visible changes

After 6 months of exposure the majority of the thalli show no significant damages. Color changes of thalli from grayish-green to whitish-brown as mentioned in former studies (TÜRK & CHRIST 1980, CHRIST & TÜRK 1981, EGGER 1993, HUFNAGEL & TÜRK 1998) were not observed in the present studies. Only some selective and peripheral bleaching and necrosis occurred. Some isolated thalli were invariably shriveled and cracked.

The visible damage of the thalli showed only small differences between various sites and expositions. Visible differences could be made out at site Gnigler Park (B), where the explants in the zone with lichen coverage showed an obvious growth and no visible damages whereas specimens along the raintracks showed at least peripheral necrosis. At site Kapuzinerberg (D) the thalli on the drier trunk side were better developed with a growth of about 15 % than those on the moister side with beginning necrosis. A growth of about 15 % of the exposed thalli was also observed at site Gaisberg (E).

CO_2-Exchange

The CO_2-gas-exchange of the lichens mostly had unimodal responses (i.e., first increasing, then decreasing). As an example the course of net-photosynthesis of the site Arenberg (site C) and the site Mönchsberg (site F) is presented.

At the site Arenberg the NP-rates of all specimens had a changeable course with a peak in April and than a decreasing CO_2-exchange (Fig. 1). This development correlates with the precipitation conditions. High precipitation sums had a positive effect on the vitality of the lichens.

The same trend - a higher rate in April - occured at site Mönchsberg (site F; Fig. 2), where the course of the NP-rate was generally decreasing and the most significant reduction of net photosynthesis was found. Conspicuous is the stronger reaction to high precipitation of the specimens on the moister trunk side (SA).

At site Hellbrunner Straße (A) the lichens not directly exposed along the rain tracks showed regeneration in the CO_2-gas exchange. After a decreasing NP-rate during the first 2 months it was increasing after a rain period of several days. The specimens in the rainwaterstrips show an inhibition of photosynthetic fixation. At site Gnigler Park (B) no homogeneous course was observed. The specimens along the raintracks seem to have an increasing NP-rate during the exposition period.

At site Kapuzinerberg the specimens on the moist side (W-sided with mossvegetation) show a similar trend with an increasing NP-rate till April and than a relatively striking reduction. The dark respiration rate however was steady increasing.

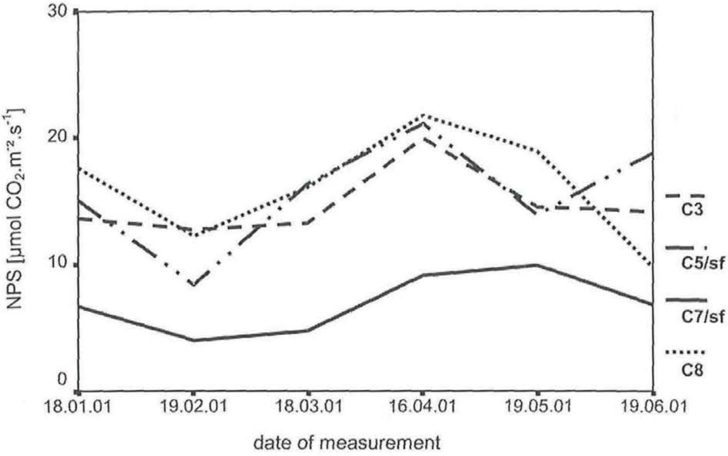

Fig. 1. NP-rates of 4 specimens at site Arenberg (site C). Samples C5 and C7 exposed to stemflow (sf).

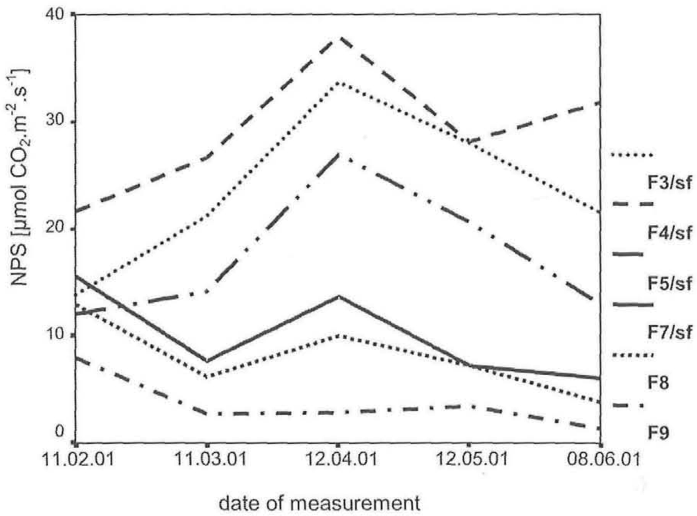

Fig. 2. NP-rate at site Mönchsberg (F).

On Gaisberg the NP-rate in contrast to the other exposure sites shows an increasing trend after an initial reduction. This correlates with a growth of the thalli at this site.

All in all the dark respiration rates took an increasing course which was mostly significant negative correlated with the NP-rates. Decreasing dark respiration rates were observed after an intensive rain period in April particularly for all explants at exposure site A (Fig. 3).

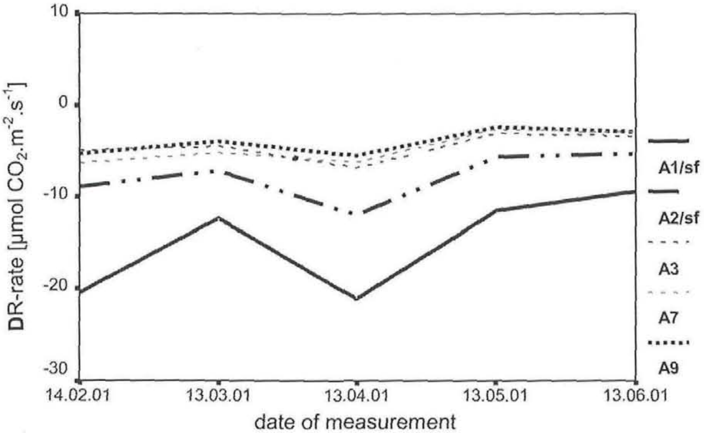

Fig. 3. Dark respiration rates at Hellbrunnerstraße (site A).

Also at other sites regardless which exposition increasing dark respiration rates occurred. Only at site Gaisberg (E), the dark respiration shows small deviations.

Chlorophyll content

No apparent changes in chlorophyll content were observed. The results were variable. In some thalli the content was higher, in others lower than the reference mean value of 0.478 ± 0.138 $mg.g^{-1}$ dry weight with no significant difference between lichens from the rainwater strips and specimens that were exposed at the drier trunk side. At the sites Hellbrunner Str. (A) and Mönchsberg (F) the lichens exposed in the rainwater strips had a conspicuous low quotient between Chla/Chlb. This suggests that Chla was reduced and a phaeophytinization of chlorophyll pigments had happened. This could also be supposed regarding a lower Rt-value (relation between Chla and Phae) of these specimens. At site E - Gaisberg, where the lichens even grew and looked healthy, the Chla/Chlb value was rather high.

A lower Rt-value than the reference mean value of 0.878 ± 0.171 was observed for all explants. The various sites were different. The highest Rt-values and lowest content of phaeophytin was found at the sites C, E and F.

Table 1. Chlorophyll content in relation of dry weight, Chlorophyll-a/b-Quotient and Rt-values (expressed in g Chl/Phae.g^{-1} dry weight).

explant	SA	Chl a+Chl b	Chl a/Chl b	Phae	Rt-value
ref. mean		0.478	3.009	0.494	0.878
A1	X	1.920	2.79	2.390	0.596
A4	X	0.818	1.82	0.964	0.557
A8		0.848	2.07	1.006	0.572
A10	X	0.733	2.51	0.955	0.553
B1		0.597	6.11	0.915	0.565
B6	X	0.604	1.42	0.857	0.553
B3		0.358	3.37	0.499	0.557
B8	X	0.624	6.02	1.308	0.412
C1	X	1.240	1.68	1.290	0.606
C7		0.340	4.02	0.425	0.645
C10		0.368	2.42	0.426	0.615
D1		0.497	2.45	0.643	0.552
D5	X	0.678	3.47	0.948	0.559
D9		1.001	4.19	1.470	0.554
E4	X	0.673	5.48	0.974	0.588
E9		0.469	7.39	0.603	0.69
E10		0.583	8.3	0.790	0.663
F2	X	0.428	-10.4	0.498	0.566
F5	X	0.538	-2.3	0.588	0.651
F7	X	0.665	-2.69	0.463	0.633
F8	X	0.676	1.26	0.636	0.597

At all sites we could not observe any detectable breakdown of chlorophyll in relation to the reference mean value.

Comparison of the results with climatic conditions and pollutants during exposure time

The metereological parameters precipitation and temperature registered at the weather station were related with the several exposition periods at each site. The winter months in this period were about 2 degrees warmer than the longstanding average temperatures. The precipitation was variable with peaks early in January and in the middle of April.

During the exposure time 2001 the pollution of the atmosphere caused by the registrated components SO_2, NO, NO_2 and O_3 in Salzburg were relatively low. Only in the second half of January and in February the pollutant concentration particularly of NO_2 was increased because of the weather situation with high air pressure. The highest level of contaminants was measured in January with an average daily mean value of 5.67 ± 1.68 ppb SO_2, 34.85 ± 5.88 ppb NO_2, 102.27 ± 37.94 ppb NO and 136.16 ± 43.21 ppb NO_x.

All parameters except for ozone show a similar trend with the highest values in January and a following decrease in average and maximum concentrations. SO_2 and NO_2 are strongly correlated (VAN DOBBEN & BRAAK 1999). The secundary pollutant ozone shows the opposite trend with an increasing course with higher temperatures.

In comparison with the last years a strong decrease in the concentration of sulfur dioxide was noticed.

Results of the analysis of the stemflow solution

Table 2. Ingredients of the collected stemflow from April to June 2001.

site	date	cond µS/cm	pH-value	Ca (mg/l)	SO_4 (mg/l)	NH_4 (mg/l)	NO_3 (mg/l)	Zn (mg/l)
A	30.03.01		-	-				3.9
	07.04.01		6.1	9	19	0.43	0.2	0.34
	08.04.01		6.2	5.6	10	0.3	0.14	0.32
	10.04.01		6.5	0.93	2.4	0.066	0.12	0.11
	11.04.01		6.1	5.3	10	0.15	0.13	0.11
	12.04.01		6.3	2.3	4.7	0.1	0.12	0.1
	17.04.01		6.2	5.6	12	0.086	0.15	0.12
	12.06.01		6.4		3.7		0.17	0.3
B	02.06.01	455	6.7	-				1.9
	14.06.01	145	6.5	5.7	12	<0.016	0.12	1.5
C	01.06.01	263	7.1	-	35		0.29	3
	09.06.01	175	6.6	15	17	<0.016	0.95	0.67
	12.06.01	123	6.4	-	13		0.76	0.37
	19.06.01	89	6.7	11	7	0.27	0.78	0.58
D	10.06.01	115	6.3	10	23	0.29	0.012	2.7
	15.06.01	86	5.9	12	5.2	0.012	0.16	0.9
	20.06.01	41	6.6	5.7	5.3	0.21	0.18	1.2
	22.06.01	45	6.5	4.3	3.3	0.22	0.12	2
E	01.06.01	76	6.5	7.5	4.6	0.83	0.57	1.1
	09.06.01	31	6.6	5.4	5.2	0.41	0.18	1.7
	14.06.01	69	6.7	7.5	3.4	1.2	0.14	0.57
F	10.06.01	195	6.2	25	14	2.9	5	0.58
	12.06.01	40	6.4	1.5	3.3	0.43	0.53	0.11
	20.06.01			12	5.9	1.4	1.8	0.85

The analysis of the collected stemflow solution was available only for the last month of exposition. The pH-value at all sites was moderately acid with variation from 5.9 to 7.1 (mean value = 6.42 ± 0.26).

The first collection after a rain event is more concentrated particularly in the amounts of sulphate, aluminium and zinc. Also the electrical conductivity of the solution is highest after the beginning of a rain period. The highest electrical conductivity was measured at site Gnigler Park (B) with 455 $\mu S.cm^{-1}$ and Arenberg (C) with 263 $\mu S.cm^{-1}$, at the same measure series the e.c. at site Gaisberg (E) came up to 76 $\mu S.cm^{-1}$.

Discussion and Conclusions

The major objective of the present study was to determine a possible effect of stemflow on the physiology of exposed lichens and to test a lichen transplant technique along raintracks of trees. The measuring data of the different pollutants in the study area show a slight pollution level. Thus it was not expected to get significant assessments of the effect of stemflow after the first 6 month of exposure. Apparently the duration of this study was too short because of the slight pollution.

The response of the transplanted specimens during the exposition period was insufficient. Possible differences between the vitality of lichens growing along the raintracks and outside of them were not significant. Differences in the vitality of the exposed lichens that could be attributed to effects of the stemflow were only found at the site Minnesheim Park (site B) and Mönchsberg (site F).

Results of the vitality assessment - visible changes

In our results the visible damages have not achieved high degrees and therefore it was renounced to arrange the explants into damage classes. Only some selective and particularly peripheral patches (white or red) could be seen but no really dead thalli-fragments. A beginning red discoloration could attribute to nitrate.

In comparison with the results of several other studies with *Hypogymnia physodes* in the same area (TÜRK & CHRIST 1980, EGGER 1993, HUFNAGEL & TÜRK 1998) the lichens in this study do not show these obvious chlorosis and necrosis. All in all at no site extensive bleaching of lichens was recorded. This can be explained by the lower level of SO_2.

The thallus area measured with the leaf area-meter mostly showed no large differences in time the major part of the thalli became smaller, probably not because of environmental influences but also from damages that could occur during the measuring process. In some cases, particularly at site Arenberg (C), some of the exposed specimens were damaged or eaten by animals like slugs or birds. On the other hand a growth of most of the thalli left on the tree, was observed particularly in May and June when the growth conditions for the lichens were improved. On Gaisberg (site E) an extension of the thallus area of 10 to 15 % was measured. An increase in size suggests unimpaired metabolic and reproductive functions of the lichen phycobiont.

As in our study registrated, HYVÄRINEN 1992 also found no significant differences in the morphological characters between thalli of *Hypogymnia physodes* on the N and S sides of trunks. He emphasized humidity as a predictor of morphological variation.

The growth rate of the thallus can alter between site types but it is presumably higher under moister conditions (HYVÄRINEN 1992).

CO_2-measurements

A correlation of gas exchange-rates and humidity was noticeable at all sites. A period with high precipitation had a positive effect on the vitality and led to higher NP-rates and lower DR-rates. An inhibition of photosynthetic fixation and an increasing DR-rate were observed for the majority of the specimens in the winter period when precipitation was low and the degree of atmospheric pollution slightly higher. The lichen response depends on the frequency and duration of the deposition episodes and recovery periods, as well as of micro-environmental factors such as humidity, light and temperature fluxes.

Particularly in summer the location of Salzburg in the Salzach-valley causes windsystems with nightly SE-winds and N- to NW-wind during the day. These wind streams bring better conditions of air exchange and thus an improvement of air quality (MAHRINGER 1978).

SO_2 emission in the Salzburg area is caused mainly by heating of private homes, some industrial sources and car exhausts. So the deposition of SO_2 shows the highest amounts in the winter months as well as the other main pollutants (apart from ozone which increases with higher temperatures). The traffic is the predominate source for dust load.

As also suggested from TÜRK & CHRIST 1980 the increasing DR-rate in May could be explained by higher temperatures.

TRETIACH & CARPANELLI 1992 found that the CO_2 exchange rates are very variable within a population of the same dimension-class growing under similar ecological conditions because of different chlorophyll content and different metabolism among the thallus portions. Even among samples of the same dimension-class, collected under the same ecological conditions, a marked variability in gas exchange rate and optimal water content is usually found. The high variation of CO_2-exchange rates and chlorophyll content were also observed in the present study.

Chlorophyll content

The intensity and area of discoloration of epiphytes, and the deposition trend of acetone soluble substances in the lichen indicate that these changes are directly related to the levels of pollution (LEBLANC & RAO 1973). The acetone-soluble substances which are hydrophobic in nature perhaps upset the moisture balance of the lichen and consequencly cause chrinkage and detachment of its thallus margins (LEBLANC & RAO 1973).

Reduction in chlorophyll content and phaeophytinization of chlorophyll pigments were observed in fumigations with SO_2, HF and NO_2 (FIELDS 1988). PUCKETT & al. 1973 using aqueous SO_2 reported that chlorophyll destruction was a function of pH, with very little destruction at a pH of 5.3 or higher but with a harp increase in chlorophyll destruction when the pH was lowered from 5.3 to 3.7 (FIELDS 1988). The pH-value of the stemflow solution generally was moderately acid to neutral (5.9 to 7.1). TÜRK & al. 1974 found that even a moderately basic solution can have a detrimental effect on the acidophilic *Hypogymnia physodes*.

In the present study the absolute values of chlorophyll content were not expressive. It was noticeable that the reference lichens showed relatively high concentrations of phaeophytin. The mean value of 0.494 ± 0.249 was a higher value than Chla. This suggests that some chlorophyll degradation had happened before the exposition. The Rt-value showed a reduction after exposition. The Chl a/Chl b quotient was higher in specimens with no visible damage.

Stem flow analysis

The results of this analysis suggest that the solution at the beginning of a rain event is more concentrated. Particularly the values of sulphate, aluminium and zinc show this trend.

The electrical conductivity shows significant differences between the sites. This parameter indicates dust immission and has higher values on places with a high volume of traffic (Gnigl, Arenberg) whereas on Gaisberg on a position with little traffic comes to significant lower values. Also the measurements of Ca and SO_4 correlate with this distribution.

One must take in consideration that during the phases of thallus desiccation the concentration of the chemical components increases within the thalli. Thus it is impossible to conclude from the values measured in the solution on the damaging capacity on the lichens.

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