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EFFECTS OF AIR POLLUTANTS ON THE GROWTH RATES OF LICHENS IN LINZ, UPPER AUSTRIA

(65 Abbildungen)

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SUMMARY

Lichens, an association between a fungal partner and one or more algal or cyanobacterial partners, have been used successfully as bioindicators for a long time. The advantage of bioindication is that a mixture of harmful substances and its direct effect on living organisms can be observed (Franzen et al. 2002). Since the beginning of the nineteen-nineties a decrease in the immission concentration of many harmful substances has been detected. In general, the concentration of acidic noxious gases has diminished in Central Europe. At the same time, the emission of nitrogen-containing airborne components, such as ammonia, increased. The number of neutrophytic and eutrophication indicating lichens has rised. Additionally Kienesberger et. al. 2007 showed that the actual immission load is mainly caused by airborne nutrient compounds. Nutrient tolerant species profit from this process which results in an increase of neutrophytes and indicators of eutrophication. This outcome strongly suggests a direct correlation to the increasing pollution by nitrogen compounds during the last decades. The present study was carried out to evaluate this correlation, to provide answers about the impact of airborne nitrogen compounds as NO_x and their derivatives as ammonia on the growth of selected lichen species. Another aim is to find out differences between measurement sites close to traffic and remote places that are usually not included into classical monitoring networks. On the other hand, a cost-effective and less time consuming method to investigate lichen growth will be tested. This photography-based method allows documentation of lichen growth over a long period (cf. McCarthy & Zaniewski 2001). Study objects for biomonitoring are the lichens *Xanthoria parietina*, *Phaeophyscia* *orbicularis* and *Parmelia sulcata.* The different annual growth rates of *Xanthoria parietina*, *Phaeophyscia orbicularis* and *Parmelia sulcata* compared to the impact of traffic will give some evidence for their performance under pollution stress. The major results of this work is that the annual growth of *Phaeophyscia orbicularis* increases with higher traffic impact whilst *Xanthoria parietina* shows a higher variation in its reaction. The growth rate of *Parmelia sulcata* decreases with higher traffic density. According to the growth of the single lichen species on the different investigation sites, a strong dependence on the availability of water through precipitation is assumed. The investigated lichens show different responses to airborne nitrogen compounds according to the kind of species. The beneficial impact on the growth rate of the lichens, attributable to need of nutrient uptake during wet occasions and the negative effects of airborne nitrogen compounds which are also incorporated during wet periods, is depending on the type of lichen.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Lichens and bioindication

Lichens, a symbiosis between a fungal partner and one or more algal or cyanobacterial partners, have long been used successfully as bioindicators. The fine equilibrium between the single partners gives these organisms a competitive edge and enables them to expand into extreme habitats. The reason why they react that fast on pollution is because they accumulate diverse substance groups and have no active mechanisms to eliminate these compounds again (Kricke 2006). Bioindication has the advantage that a mixture of harmful substances and its direct effect on living organisms is assessed (Franzen et al. 2002). Because of their sensitivity, lichens are an important factor in bioindication (Ahmadijan 1993). According to Türk (1991), biomonitoring with lichens can be done as passive biomonitoring (lichen mapping), active monitoring (lichen transplantation) and accumulative monitoring (measurement of heavy metals and radionuclide).

1.1.1 Biocoenosis with fragile biological equilibrium

Lichens are no uniform organisms, but a biocoenosis between a mycobiont (mostly ascomycetes, rarely basidiomycetes) and a photobiont (algae and/or cyanobacteria, Ahmadijan 1993). The fungal hyphae build the majority of the lichen thallus and therefore the mycobiont absorbs most of the nutrients and water. Only the photosynthetic partner is able to fix carbon, which is why the mycobiont is dependent on carbon derived from the photobiont. Therefore it is on behalf of the mycobiont to ensure the photobionts nutrial status. Translocation of metabolites between the associated partners may be controlled by repeated drying and wetting of the thallus (Dahlman 2003). Another characteristic of the lichen relationship is their relatively slow growth, even under good environmental conditions (Masuch 1993). The sensitivity of lichens against air pollution and therefore their suitability for bioindication is caused by the following factors (Vorbeck & Windisch 2001):

- The metabolic relationship between fungal partner and photobiont is relatively fragile. Accumulation of toxins or changed nutrient availability can affect the symbiotic balance and therefore cause a breakdown of the lichen association (Egan 2010).
- Damages can only be regenerated slowly due to their poikilohydric nature.
- Lichens do not have a cuticula, stomata or any other regulatory mechanisms to control the uptake of pollutants. Pollutants can enter the lichen thallus through the whole surface.
- Pollutants are accumulating because of the slow and permanent growth (Mohr 2007) and because there are no active excretion mechanisms and special exclusion organs.

Even at low temperatures, lichens can be metabolically active and therefore can be damaged in winter too (Vorbeck & Windisch 2001).

1.1.2 Indicating mixtures of pollutants

Technical measurement of air pollutants indicates the concentrations of singular pollutants on a defined place at a defined time. The overall pollution load on the living nature can therefore only be estimated. Bioindication with lichens shows a real effect of air pollutants on living organisms, lichen mapping additionally shows the development of the lichen community over long time periods. Both methods complement each other and therefore allow a more comprehensive estimation of air pollution (Franzen et al. 2002).

1.1.3 Long tradition and low costs

Lichens are within the first organisms, which were used for bioindication (Kostka-Rick et al. 2001). More than hundred years ago, the Scandinavian lichenologist Nylander found a relationship between anthropogenic air pollution and the decline of lichens in urban areas (Nylander 1866). Similar observations were made by Arnold (Arnold 1891, 1892, 1897, 1899, 1900 a, b) in his studies in Munich. In 1926, the Swedish Lichenologist Sernander developed the terms "lichen desert", "struggling zone", "transition zone" and "normal zone" to describe the appearance of lichens in and around cities (Sernander 1921). Many other publications show the importance of lichens in bioindication: Nowak 1973, Türk & Wittmann 1988, Kirschbaum & Windisch 1995, Kirschbaum & Wirth 1997, Stapper et al. 2000, Nimis 2002, Nimis & Purvis 2002, Gombert et al. 2003, Klumpp et al. 2004, Stapper & Kricke 2004, Nobel et al. 2005, Nash III 2008, Nobel et al. 2008 a, Nobel et al. 2008 b, De Bruyn et al. 2009, Schnell & Stapper 2009 to mention only a few.

1.2 Air pollutants

1.2.1 Air pollutants and lichens

Effects of air pollutants on lichens can result in a reduced reproductive potential. Sometimes under influence of pollution, production of soredia and isidia increases. Growth and morphology can also show changes as change of growth rate, discolouration or bleaching and cortex cracks. Pollutants can interrupt photosynthesis and ion exchange capacity and can affect membrane integrity (Egan 2010). An overview of the pathways of main air pollutants and their effect on lichens is given in figure 1. Under influence of atmospheric conditions, photochemical precesses and other compounds, emitted pollutants are transformed an deposited on the lichen thallus. The thallus surface seems to play an important role. For example, the tolerance against SO_2 and acids seems to be connected with the hydrophobic qualities of the thallus surface. *Xanthoria parietina* is moderately sensitive against acid precipitation and has a slightly hydrophobic surface according to Hauck 2009. As Hauck 2010 showed, tolerance to high nitrogen concentrations also depends on the ability of the photobiont to provide enough carbon skeletons to assimilate ammonia.

1.2.2 The effects of airborne nitrogen compounds on lichens

Usually, NO_x are seen as the main cause of atmospheric nitrogen load, but nitrophile plant species still increase while emissions decrease. Many lichen species which were found on trees in urban areas have been known formerly nearby farms (higher ammonia concentrations from animal husbandry). Frahm 2008 pictures the impact of catalytic converters on lichen species and showed that they emit ammonia.

Anyway, most frequent emissions in traffic are NO_x and in small amounts SO_2. Under influence of water vapour and ozone, these transform into ammonium nitrate (NH_4NHO_3 content of many fertilizers) or ammonium sulphate ($(NH_4)_2SO_4$); Frahm 2008). Ammonium nitrate has a particle size of 1 µm and puts in average 50 % of particulate matter (Frahm et al. 2009). The authors also described the importance of ammonia as most relevant nitrogen source for lichens. As ammonium nitrate it is deposited on lichens through dry deposition. Because ammonium nitrate is a salt, nitrophytes have higher osmotic values. Therefore they are not necessarily indicators for nitrogen but for drought. The lichen has to take up water from this concentrated salty dilution which necessitates high osmotic values. The conductivity of cell sap is much higher in nitrophytic species than in neutrophytic. This seems to be coherent as *Xanthoria parietina*

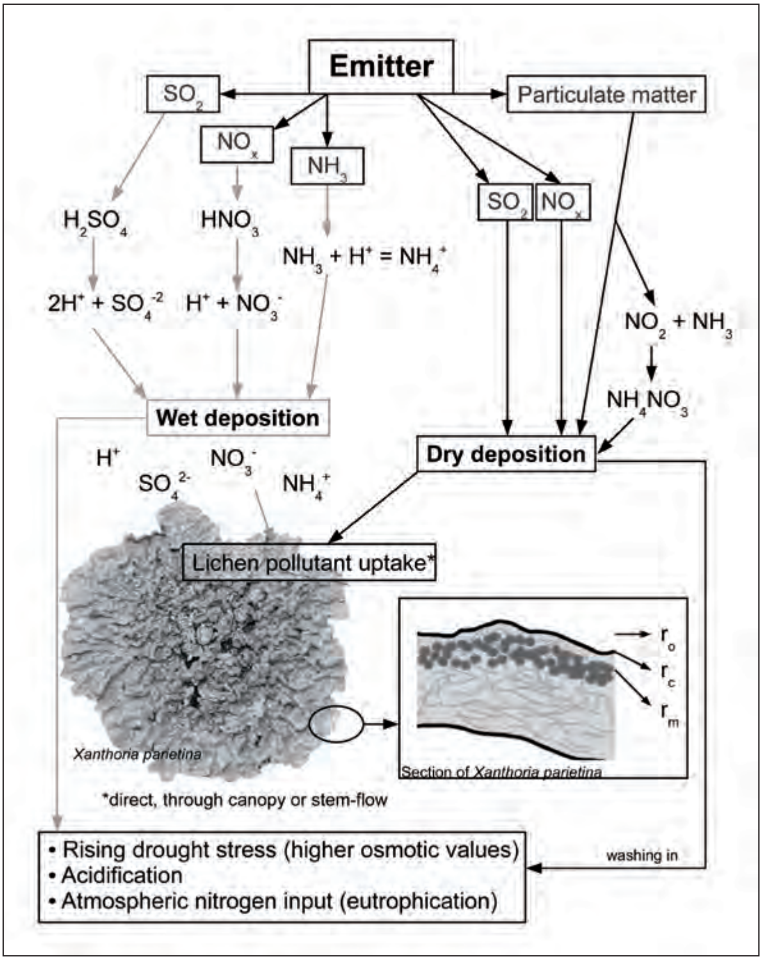

Fig. 1: Effects of air pollutants on lichens (simplified, according to various authors).

is very common in coast regions without nitrogen influence. In dry coastal areas of Malta the nitrophytic lichen *Xanthoria parietina* is very common, but the occurrence of *Ramalina lacera* excludes the impact of nitrogen deposition. Therefore it can be said, that nitrophytes are in fact xerophytes. The increasing load of particulate matter in form of dry deposition causes still an rise in nitrophytic lichen flora. Dry deposition plays an very important role in case of eutrophication. Usually it is said that NO_x dissolve to nitrous acid (HNO_2) in rain water. This can only happen during rain or high air humidity. In dry periods NO_x bind with ammonia. It is often assumed that nitrophytes increase because of rising bark-pH values as response to particulate matter deposition. *Xanthoria parietina* can also growth on birch tree which has a acid bark reaction. Ammonium nitrate shows a acid reaction. Hence it can be said, that nitrophytes are no basiphytes (FRAHM et al. 2009).

1.2.3 Decreasing role of $SO_{2,}$ importance of airborne nitrogen compounds

Since the beginning of the nineteen-nineties a general decrease in the immission concentration of most harmful substances has been observed in Upper Austria (AMT

d. Oö. Landesregierung 2010). In general, the concentration of acidic noxious gases, and likewise their impact on tree bark, has diminished in Central Europe since the nineteen-eighties and by association their deleterious effects on the European conifer forests (Franzen-Reuter 2004). In contrast, the effects of airborne nutrient components have increased simultaneously. Acidophytes have not benefited from this process, because they are in part nitrogen intolerant. They often have not been able to bear competition with other species as well. On neutral barks eutrophication indicators greatly benefit from this development. Acidophytes are less competitive to eutrophication indicators and suffer from nitrogen and other fertilizing immission (VDI 2005).

2 RESEARCH OBJECTIVES

2.1 Impact of airborne nitrogen compounds: NO_x and derivates as ammonia

In Central Europe, concentration of harmful acidic gases decreased since the 1980s and simultaneously the impact on the tree barks as well as on the trees themselves. The influence of airborne nutrient compounds increased in the same time (VDI 2005). There was a rise in diversity of nitrophilic and eutrophic lichen species. Acidophytic lichens do not profit from this process. They are mostly intolerant to nitrogen and therefore less competitive under eutrophic conditions losing ground to other neutrophytic/nitrophilic lichens or to mosses (VDI 2005). Nitrophytic species still increase, even when nitrogen emissions decrease (Frahm et al. 2009). Many studies about lichen monitoring with lichens agree, that airborne nitrogen compounds are the most effectual air pollutant at the moment (e.g. Van Herk 1999, Frahm & Solga 1999 and Franzen-Reuter & Stapper 2003, Frahm et al. 2009). Nutrient tolerant species profit from this process which results in an increase of neutrophytes and indicators of eutrophication. According to Franzen-Reuter 2004 airborne nitrogen compounds can effect lichens directly and indirectly in form of NO (nitrogen monoxide), NO_2 (nitrogen dioxide), NH_3 (ammonia) as dry deposition and NO_3 (nitrate) and NH_4 (ammonium) as wet deposition. The following question is one aim of the present study: Is there an impact of airborne nitrogen compounds as NO_x and their derivatives as ammonia on the growth of selected lichen species in Linz?

2.2 Differences between measurement sites: close to traffic related to remote ones

Previous investigations in Linz: More than 40 years ago, Bortenschlager & Schmidt (1963) already investigated the lichen distribution in Linz with regard to air pollution. Based on the method of Beschel (1958), characteristic lichen communities of singular species were used to describe the lichen zones. Another immission-ecological study was performed by Hoislbauer in the year 1979, was using the method of Beschel in combination with the IAP (Index of Air Purity) method. In this study, he analysed the lichen vegetation on pear and apple trees (Hoislbauer 1979). He showed that there were no clear air quality zones. Lichen desert and combat zone reached an area of 100 km^2. In the years 1986-1988, the city of Linz again was investigated again (Türk et al. 1994) showing that areas with high pollution loads again increased. From January 2006 to January 2007 a study of air quality in Linz was done by Than & Türk (2008). Evaluation of this results showed that there were still no areas with very high air quality. Sensitive species, like *Evernia prunastri* were only occurring damaged or in poorly developed stages. *Pseudevernia furfuracea* and *Usnea sp.* were just found in

1 % of the investigated area. Figure 2 shows, that zones of moderate and low air quality are dominating the city. High air quality was detected in the southern outskirts of the Mühlviertel and south of Traundorf which are less affected by emissions and inversions. In this areas, foliose lichens as *Parmelia sulcata* and *Parmelina tiliacea* occur, but are often damaged. Nevertheless the zones of high quality reached a larger expansion than in the investigated period of Türk et al. 1994. But still the dominance of eutrophic species as *Phaeophyscia orbicularis, Physcia adscendens* and *Xanthoria parietina* increased dramatically. Very low air quality was found in 2 % of the investigation area,

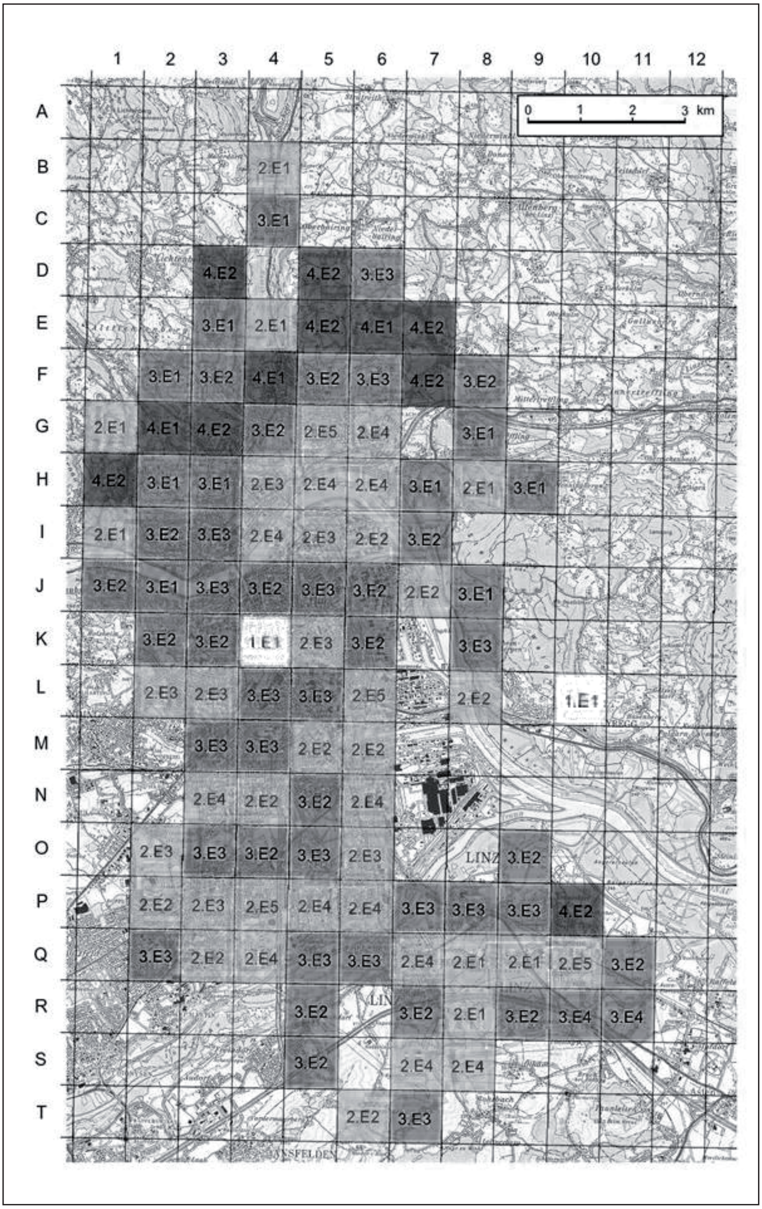

Fig. 2: Air quality in Linz 2008 (air quality: 1: very low, 2: low, 3: medium, 4: high, 5: very high. eutrophication: E1: very low, E2: low, E3: medium, E4: high, E5: very high) (Than & Türk 2008).

where trees were generally lichen-free with exception of only a few thalli of *Phaeophyscia orbicularis* and *Physcia adscendens*. The influence of eutrophic air pollutants ranged from low to high. Overall, in comparison to previous investigations, lichen deserts decreased and zones of low and moderate air quality increased in Linz. The authors assumed that factors like distance to streets seem to be more important than distance to main emitters (Than & Türk 2008). Similar observations were made by Bruteig 1993, who described effects of nitrogen pollution in vicinity to major emitters. Additionally Kienesberger et. al. (2007) could show that the actual immission load is mainly caused by airborne nutrient compounds. The following questions are part of the present study:

✻ Are there differences between measurement sites close to traffic and remote ones that are usually not resolved in classical monitoring networks?

✻ Testing of a cost-effective and less time consuming method to investigate lichen growth.

✻ Documentation of lichen growth over a long period.

3 INVESTIGATION AREA

3.1 Geographical location

The municipal area of Linz, comprising approximately 96 km², is located near the Danube at an altitude of about 260 m to 540 m above sea level (Heber et al. 1992). In the northern region the basin of Linz is surrounded by the plains of the Mühlviertel (Heber et al. 1992), while the Danube cuts through in Linz between the Kürnberger Forest and the Mühlviertel flowing into the lowland. In the North-west of Linz, the foothills of the Bohemian Massif, which are situated to the south of the Danube, the Kürnberg, Pöstlingberg, Lichtenberg, Magdalenenberg and Hagerberg in the north, and the Pfenningberg in the east, border to the basin (Umweltbundesamt 2004). The Kürnberg lies at an altitude of 526 m above sea level, the Freinberg at 405 m, the Pöstlingberg at 539 m and the Pfenningberg at 616 m. The municipal area extends in a south-eastern direction beyond the floodplain of the Danube into the estuary plain of the river Traun (Heber et al. 1992). Steyregg is situated to the east of the industrial area of Linz (with Voestalpine Stahl GmbH, a steel industrial plant) and to the south of the Pfenningberg (Umweltbundesamt 2004).

3.2 Climatic conditions in Linz

3.2.1 Overview

The orographical situation of Linz, which is characterised by the city's location in a basin and by deep clefts (e.g. Haselgraben), creates complicated meteorological conditions (Mursch-Radlgruber 1997, 2002). In general, the mixture and quality of the air depend, amongst other factors, on temperature distribution, wind-force, wind direction and precipitation. As the shape of the landscape may deflect or decelerate air currents and generate temperature differences, it has a significant effect on atmospheric stirring and thus on the immission concentration of pollutants (Marhold 2003). Apart from the orographical situation, the climate plays an important role as well. Linz is located in the humid-temperate and warm-temperate climatic zone. However, Linz possesses a typical urban climate characterized by higher temperatures in the city-area than in the surrounding countryside. This urban warming is caused by an input of heat and soot from industry, traffic and private heating, a reduced radiation from haze and absorption from dark surfaces (Heber et al. 1992).

3.2.2 Status of wind and aeration

The prevailing wind direction in Linz is in 65 to 85 % from west and north west winds (Umweltbundesamt 2004). However, only the strong west winds can penetrate into the basin of Linz, whereas the other winddirections are diverted by the landscape surface. In the winter half-year, south and southeast winds are of greater significance (Heber et al. 1992). Under the influence of east winds, the Pfenningberg shifts the wind direction to the south east, so that industrial emissions are transported towards the city centre. When southwest winds are prevailing, the Pfenningberg channels the air across the Trefflinger Sattel towards Asten (Marhold 2003). In addition, the air flow between the city and the surroundings is obstructed by densely with buildings covered areas (Heber et al. 1992). The mean wind speed accounts for approx. 3 m/s in Linz-Hörsching and for 1 to 2 m/s in the municipal area of Linz and in Steyregg. While east and west winds show a mean wind speed of about 2.5 to 3 m/s, the slower north and south winds blow at a rate of 1 to 1.5 m/s. Calms (wind speeds lower than 0.5 m/s) occur in the municipal area at a frequency of 35-40 % (Umweltbundesamt 2004). In summer, a strong cold air current across the Haselgraben transports pollutants from remote places like Urfahr and farther south areas of Linz into the open basin of Linz. The effect of this reaches far into the city centre, whereas it is not detectable anymore in built-up areas farther south. Southern parts of the city are influenced by the spacious airstreams in the open basin and are generally better aerated. In the second half of the night, northern parts are only ventilated by the flow of cold air from the slopes of the hill country and by an air current from the Danube gorge (Mursch-Radlgruber 2002).

Fig. 3: Inversion layer in dilution. View of the Pöstlingberg, taken from the Pfenningberg on 13. 12. 2006, 8:00 a.m.

3.2.3 Fog and inversions

As Linz is located in a basin, calms and inversions are quite frequent, especially in autumn and winter (Umweltbundesamt 2004). The average upper limit of the inversion layer in Linz is at an altitude of about 230 m above valley level and about 490 m above sea level, respectively (Hoislbauer 1979). The inversions mostly dissolve in the morning. Pollutants are accumulating during the time until the inversion weather situation vanishes. Therefore, the highest immission load can be observed during that time of the day. The temperature gradietnt from the surroundings into the urban areas causes a suction, which draws air from the surrounding countryside and industrial areas into the city centre. When the low wind speeds due to tight clouds are accompanied by fog or high fog, hardly any thermal movement takes place within the area covered by the inversion, which reduces the dilution of air pollutants (Mursch-Radlgruber 2002).

3.2.4 Pollution load in Upper Austria and Linz

Since the beginning of the 1990s, a clear decrease in the concentrations of most imission-types has been observed. Also violations of pollution-limits decreased for the following immissions: suspended particulate matter, hydrogen sulphide and nitric monoxide. A decline in the concentrations of heavy metals and organic pollutants has also been observed (Amt der Oö. Landesregierung 2005). A comparison of the emissions from 2002 and 2008 showed a clear increase of the emissions of CO_2 and NO_x. In case of CO_2, the reason is the higher amount of emissions in production processes. NO_x emissions were increased too because of the increase of traffic. In 2004, the implementation of sulphur free motor fuel caused a major reduction of SO_2 emission. This effect was compensated by a higher emission rate in industry, so the overall SO_2 emission stayed the same (Amt der Oö. Landesregierung 2010b).

3.3 Study sites

3.3.1 Study sites with high traffic impact

Location 13 and 14: These study sites are located next to a shopping centre in Pasching, a suburb south-west of Linz. The lichen-carrying trees are directly influenced by a main road (compare Fig. 4).

Geographic data: N48°14'39,48'' E014°14'16,5'', Altitude: 280 m

Fig. 4: Surroundings of location 13 and 14.

Location 24 and 25: The phorophytes of both study sites are situated on traffic islands and directly encircled by main roads with high traffic density (Fig. 5). Close to the study sites, there is an governmental measurement location for recording immission (Linz-Neue Welt).

Geographic data: Location 24: N48°16'25,03'' E014°18'49,01'', Altitude: 260 m. Location 25: N48°16'25,98'' E014°18'49,72'', Altitude: 260 m

Fig. 5: Surroundings of location 24 and 25.

Location 26 and 27: Traffic density is also high at this study sites, even though there is not so much influence as in the previous locations (Fig. 6).

Fig. 6: Surroundings of location 26 and 27.

Geographic data: Location 26 and 27: N48°17'54,01" E014°16'3,03", Altitude: 260 m

Location 29: This study site is located on a traffic island next to a main road with a tunnel entrance close to the study site. A governmental air quality measurement location is situated nearby (Fig. 7).

Geographic data: N48°18'10,47'' E014°16'53,95", Altitude: 270 m

Fig. 7: Surroundings of location 29.

Location 30 and 31: These are strongly influenced by a main road in the centre of the city. There is a very low overall abundance of lichens. *Phaeophyscia orbicularis* occurs, but the individuals are not very well developed (cf. Fig. 8).

Fig. 8: Surroundings of location 30 and 31.

Geographic data: Location 30 and 31: N48°18'31,03" E014°17'27,01", Altitude: 260 m

Location 32: This site is located directly next to an urban highway north of the river Danube (Fig. 9). On the other side of the highway, the measurement station 24er-Turm is situated.

Geographic data: N48°19'25,91'' E014°17'53,59", Altitude: 260 msm

Fig. 9: Surroundings of location 32

3.3.2 Study sites in urban housing areas with low traffic impact

Location 01 and 02: Both study sites are situated in urban housing areas in the north of Linz, traffic influence is very low (Fig. 10).

Geographic data: Location 1: N48°20'13,49" E014°18'41,27", Altitude: 257 m. Location 2: N48°20'10,82" E014°18'38,23", Altitude: 257 m

Location 10: The study site is located in a suburb south-westerly of Linz, traffic influence is moderate (Fig. 11). In the immediate vicinity there are agricultural areas.

Geographic data: N48°15'58,05'' E014°15'9,97", Altitude: 280 m

Location 12: The surrounding area of station 12 (Fig. 12) is affected by the housing area of Wagram, a suburb south-westerly of Linz. There is a forest close to the study site.

Geographic data: N48°14'17,68'' E014°13'35,46", Altitude: 280 m

Location 20, 21, 22 and 23: These study sites are situated in an park south of the city centre. The park is a water protection area

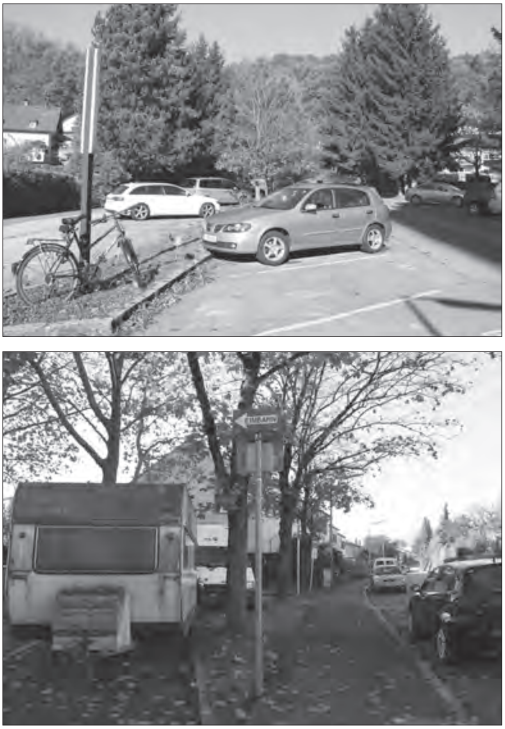

Fig. 10: Surroundings of location 01 and 02.

Fig. 11: Surroundings of location 10.

Fig. 12: Surroundings of location 12.

for Linz, therefore traffic impact is quite low (Fig. 13).

Geographic data: Location 20, 21, 22 and 23: N48°15'43,36'' E014°18'23,45'', Altitude: 260 m

3.3.3 Study sites without direct traffic impact

Location 05, 07, 08 and 09: These study sites are located in Steyregg, a suburb east of Linz (Fig. 14). Direct influence of traffic is

Fig. 13: Surroundings of location 20, 21, 22 and 23.

very low, there are only small roads. Because of the orographical situation, there could be a strong influence by the industrial areas on Steyregg.

Geographic data: Location 05: N48°17'35,8" E014°21'4,03", Altitude: 500 m. Location 07: N48°17'28,67" E014°22'43,14", Altitude:380 m. Location 08: N48°17'58,67" E014°22'23,32", Altitude: 440 m. Location 09: N48°17'58,67" E014°22'23,32", Altitude: 440 m

Location 15: Measurement site15 is located near a small road n the north of Linz. Measurement was only possible from November 2008 to October 2009, because the tree was cut in November 2009.

Location 16, 17, 18 and 19: are situated in the south west of Linz nearby the Pichlinger lake. The area is a place of local recreation, therefore the direct influence of traffic is quite low.

Geographic data: Location 16, 17: N48°12'12,22" E014°23'3,06", Altitude:

Fig. 14: Surroundings of location 05, 07, 08 and 09.

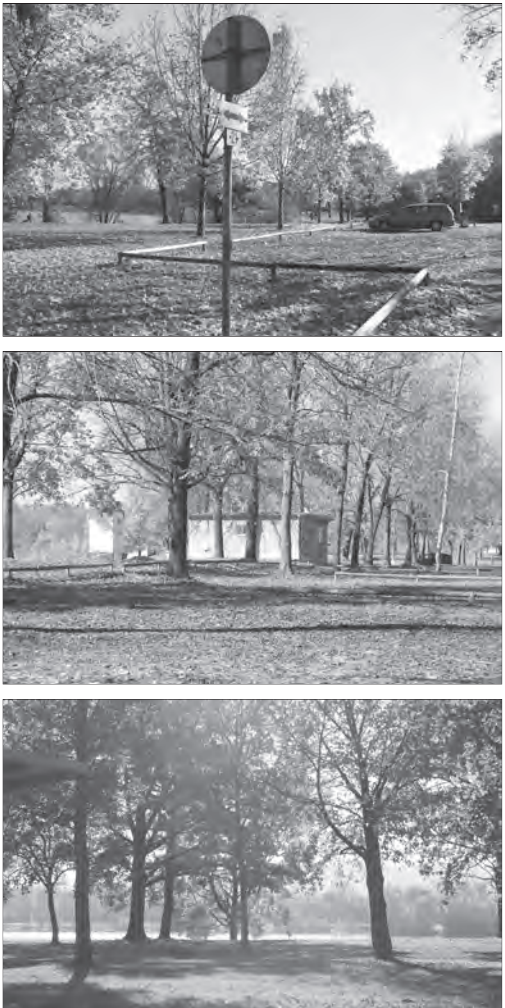

Figure 15: Surroundings of location 16, 17, 18 and 19.

245 m. Location 18: N48°14'23,03" E014°23'15,06", Altitude: 245 m. Location 19: N48°14'24,55" E014°23'6,04", Altitude: 245 m

3.3.4 Dismissed study sites

Location 03, 04, 06, 11 and 28 have been dismissed.

4 METHOD

4.1 Sampling design

4.1.1 Selection of the lichen carrying trees

The selected trees varied depending on the sampled area. *Pyrus communis, Malus domestica* and *Juglans regia* were found mainly in the rural areas of the city. Species such as *Tilia platyphyllos*, *Tilia cordata*, *Acer platanoides*, *Fraxinus excelsior* were found along streets in the urban areas. The fractions of lichen-carrying trees in Linz were estimated by THAN & TÜRK (2008) as shown in figure 16. The trees stand freely and receive at least some direct sun radiation during the day. In 1,70 m height, the circumference is between 70 and 280 cm. Trees that are injured or affected by whitewashing or grazing animals have not been used for the investigation. Ideally only trees of one single species are used. Because this was not possible, trees with similar bark reaction were selected. The selection of the trees was complied with the guideline VDI 2005.

4.2 Investigated lichen species

4.2.1 *Xanthoria parietina* (L.) TH. FR. (Fig. 17)

Xanthoria parietina is typically growing on subneutral, more the less nutrient-rich habitats. It is quite resident against air pollutants and can also grow on limy, eutrophicated rock surfaces, on anthropogenic substrate as the epithet *parietina* = "on walls" indicates (WIRTH 1995). According to KIRSCHBAUM & WIRTH (1997) it prefers eutrophic barks of freestanding trees and shrubs with high pH-value. Common names of *Xanthoria parietina* are "common orange lichen", "yellow scale", "maritime sunburst lichen" or "Gewöhnliche Gelbflechte" (in German). *Xanth. par.*

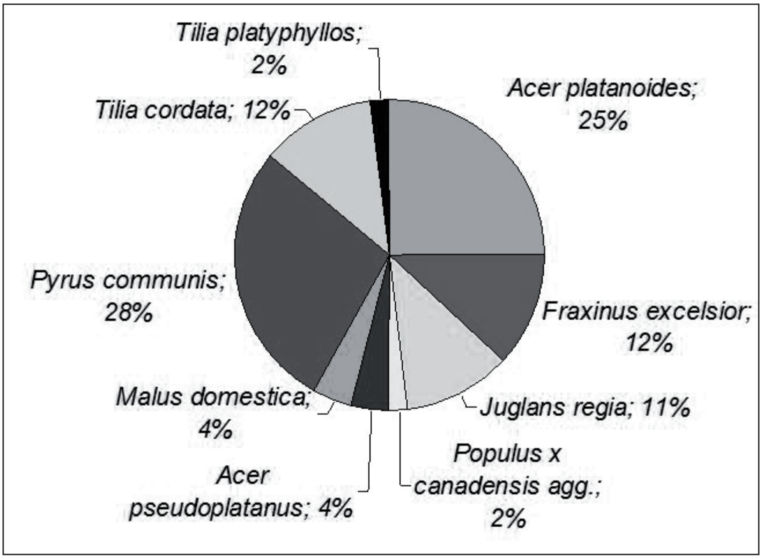

Fig. 16: Fractions of lichen carrying trees in Linz (THAN & TÜRK 2008).

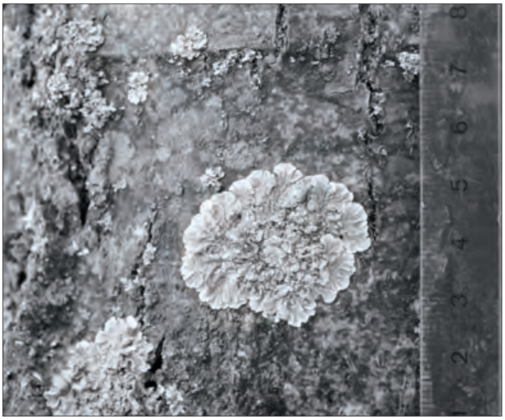

Fig. 17: *Xanthoria parietina*

tolerates high concentrations of NH_3 and NH_4 (Nash 2008) which is also supported by Frahm et al. (2009) who pointed out that ammonia from catalytic converters is the main nitrogen source for lichens. Windisch (2010) showed that *Xanthoria parietina* is more frequent near high traffic streets than on remote places, which supports this thesis. Than & Türk (2008) found that the yellow scale is second most common lichen in Linz and is distributed in 92 % of the city area.

4.2.2 *Phaeophyscia orbicularis* (Neck.) Moberg (Fig. 18)

Kirschbaum & Wirth (1997) describe *Phaeophyscia orbicularis* (Necker) Moberg as an morphologically variable foliose lichen, which prefers nutrient-rich, dust-impregnated barks of deciduous trees. Wirth (1995) specifies it as highly tolerant against eutrophication and other pollutants. Like *Xanth. parietina*, *Ph. orbicularis* prefers habitats near streets against remote places (Windisch 2010). Franzen-Reuter (2004) showed that the occurrence of *Ph. orbicularis* increases with higher nitrogen deposition. *Ph. orbicularis* is also promoted by typical stress factors in urban areas as traffic immissions and overheating (Schnell & Stapper 2009). Janssen et al. (2007) observed that *Ph. orbicularis* seems to act as an indicator for dry deposition and therefore particulate matter. Than & Türk (2008) showed that *Ph. orbicularis* is one of the most important lichen species in Linz with a frequency of 82 %.

4.2.3 *Parmelia sulcata* Taylor (Fig. 19)

Parmelia sulcata is a pale gray to greenish-gray foliose lichen. It consists of flat, overlapping branches which are attached to the bark tightly. The lower surface is dark and covered by blackish rhizines. *Parmelia sulcata* is a very common and toxitolerant epiphytic foliose lichen and has broad ecological amplitude. Nutrient-rich barks are preferred habitats (Wirth 1995). In Linz, *Parmelia sulcata* is common in 64 % of the city area. The innermost parts of the city are avoided though and individuals show clear

Fig. 18: *Phaeophyscia orbicularis*

Fig. 19: *Parmelia sulcata*

damages in areas with high immission load (Than & Türk 2008).

4.2.4 *Parmelina tiliacea* (Hoffm.) Hale (Fig. 20)

According to Wirth (1995), *Parmelina tiliacea* prefers moderately nutrient-rich barks of free-standing deciduous trees in euphotic habitats. Than & Türk (2008) found out that *P. tiliacea* is common in 29 % of the city area in Linz. It barely occurs in the inner parts of the city and is common in rural areas in the north of Linz. Kricke (2002) also identifies *Parmelina tiliacea* as a "city-avoiding" lichen.

Fig. 20: *Parmelina tiliacea*

4.2.5 *Melanohelia exasperatula* (Nyl.) O. Blanco et al. (Fig. 21)

According to Kricke (2002), *Melanohelia exasperatula* is moderately tolerant to urban habitats. It is common on deciduous trees with moderate nutrient rich bark. It tolerates moderate to quite high eutrophication. Than

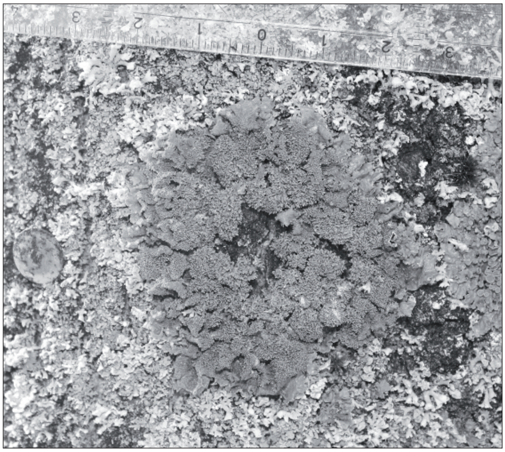

Fig. 21: *Melanohelia exasperatula*

& Türk (2008) found a frequency of 59 % in Linz but showing strong damages in areas with high pollution, it shows strong damages.

4.3 Measurement of lichen growth

Lichens on 32 different measuring sites were photographed over a period of 20 months and the images transferred to a computer. The photographs were taken with the digital reflex camera Canon 1000D with the objective EFS 18-55 mm. The photographs were stored on flash storage cards in highest quality as JPG-files. With the open source software "GNU Image Manipulation Program" Version 2.6 (GIMP, GIMP Developement Team 2010), measurement of thallus area has been done. McCarthy & Zaniewski (2001) used similar digital image analysis to obtain different measures of lichen crusts on rock surface (lichenometry). Traditional methods in lichenometry are time consuming, whereas digital analysis requires less field time. McCarthy & Zaniewski (2001) used Adobe Photoshop and a GIS software for the analysis. The GIMP software is freely distributed and therefore a cost-effective tool to investigate lichens. GIMP has been developed for tasks as photo retouching, image composition and image authoring and works on many operating systems (GIMP Developement Team 2010).

The program additionally offers different possibilities that can be used to measure diameter, growth of single lobes, dimension of damages, performance under competition with other species and number of fruiting bodys which are not aim of the present study. Anyway, the photographic data can be stored and reused in case additional questions occur. The technique requires smooth bark surface wherever applicable. Clear colour differences between lichen thallus and bark surface simplify the analysis on the computer. Analysis with GIMP2.6 can be used for both crustose and foliose lichens as their thallus is more the less smooth. According to shrub lichens, the method can be only used to measure dominance on the tree bark. The great advantage of this method is the comparatively simple handling, the possibility of collecting large number of samples in a short time, the accuracy in detecting slight changes in growth and the chance to use the photographic data for following investigations.

4.3.1 Correction of possible error sources:

✻ Swelling error: Because lichens are poikilohydric organisms, their status of swelling depends on the surrounding air humidity. The more the lichen is swelled, the bigger is its thallus size. To minimize this possible measurement error, the lichens have been soaked with Aqua dest. for 15 minutes before the picture was taken. This was also suggested by Polony & Türk (1990).

✻ Possible parallax errors have been reduced by focusing directly on the whole thallus surface. Therefore lichen thallus and film layer were approximately parallel for the following exposures.

✻ To prevent enlargement errors, a centimetre scale was photographed next to the investigated lichen.

4.3.2 Calculation of the thallus area:

As parameter for the lichen growth, the thallus surface area was used. Determination of the thallus area is described in the following. The photograph was opened with the program GIMP2.6. To view the total pixel number of the whole picture, the window "histogram" was opened too (Fig. 22).

With the tool "create path", the outline of the lichen is traced by setting single anchor points (Fig. 23). When the process is finished, a selection is to be done from the path. Now, the number of pixels of the lichen area is displayed in the window "histogram". The number of pixels equates to the lichen area.

Fig. 22: Graphic user interface of GIMP2.6 with displayed lichen photograph with the window „histogram" (bottom left).

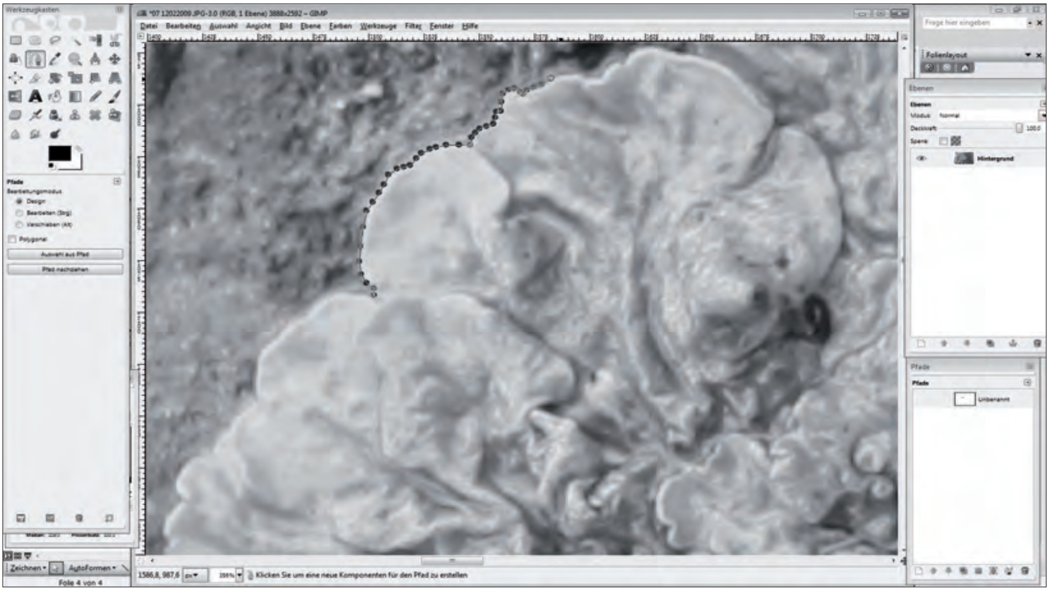

Fig. 23: Process of setting single anchor points in GIMP2.6.

In order to avoid the enlargement errors, a centimetre scale was also photographed next to the lichen as can be seen in Fig. 24. The sale is used to calculate the real area of the lichen. The tool “ruler” implemented in GIMP2.6 was used to measure the distance of 1 cm on the photograph in its digital form. The number of pixels displayed below the photograph equates to the distance of 1 cm and can therefore be used to calculate the lichen area.

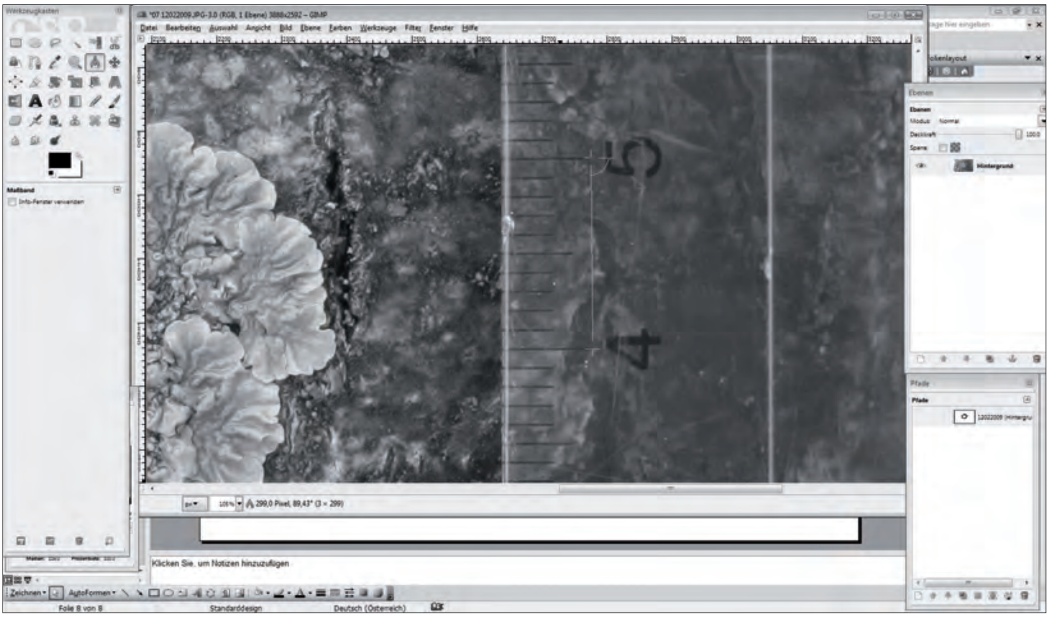

Fig. 24: Number of pixel equates to lichen area. Calculation is carried out with a ruler.

5 RESULTS

5.1 Growth rates of the different measuring sites

5.1.1 Location 1

The investigated lichen species on measurement site 1 was scaled twelve times and showed a growth of 2,26 cm² during the investigation period. This equates to a total growth of 55 %. Over a period of one year (February 2009 - February 2010) there was a total growth of 1,67 cm², which is 41 %. From October 2008 to April 2009, *Parmelia sulcata* increased 18 % in its thallus surface area and from April to October 2009 there was a further growth of 19 %. In the following period from October 2009 to April 2010, the surface area increased for 11 %, which was 7 % less than the year before. From July 2009 to September 2009 there was a strong increase in growth, followed by a decrease in the next measuring period. Apart from this event, the lichen growth was quite linear (Fig. 25).

5.1.2 Location 3

Investigation site 3 was only accessible on five measuring days. Between the first investigation day in October 2008 and December 2009 a major part of the inner lichen thallus broke away. This event has not been considered, because the outline of the lichen was not affected. In the first time of the measuring period, there was a strong increase of lichen size, whereas the curve flattens subsequently (Fig. 26). From April to May 2010 there was a slight decrease in lichen size. During the whole investigation period, there was a total increase in area of 2 cm², which is equivalent to 45 %. From October 2008 to December 2009 *Xanthoria parietina* gained 1,85 cm² (42 %). From April 2010 to May 2010 there was a decrease of 0,23 cm² or 5 %.

5.1.3 Location 5

Xanthoria parietina on measurement station 5 showed a continuous growth during the investigation period and reached a gain in

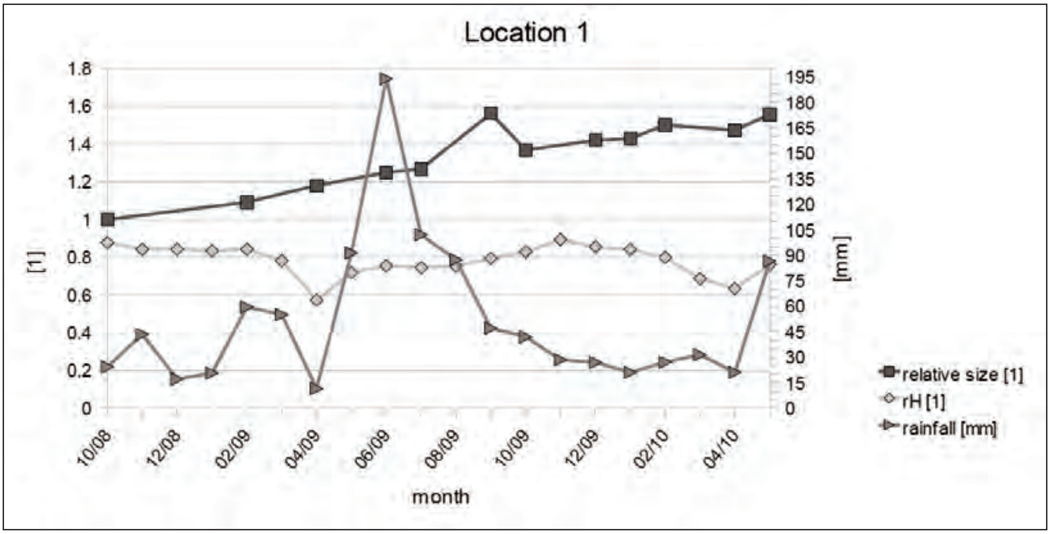

Fig. 25: Relative size of *Parmelia sulcata* on location 1, relative air humidity (rH) and rainfall (average values of Linz).

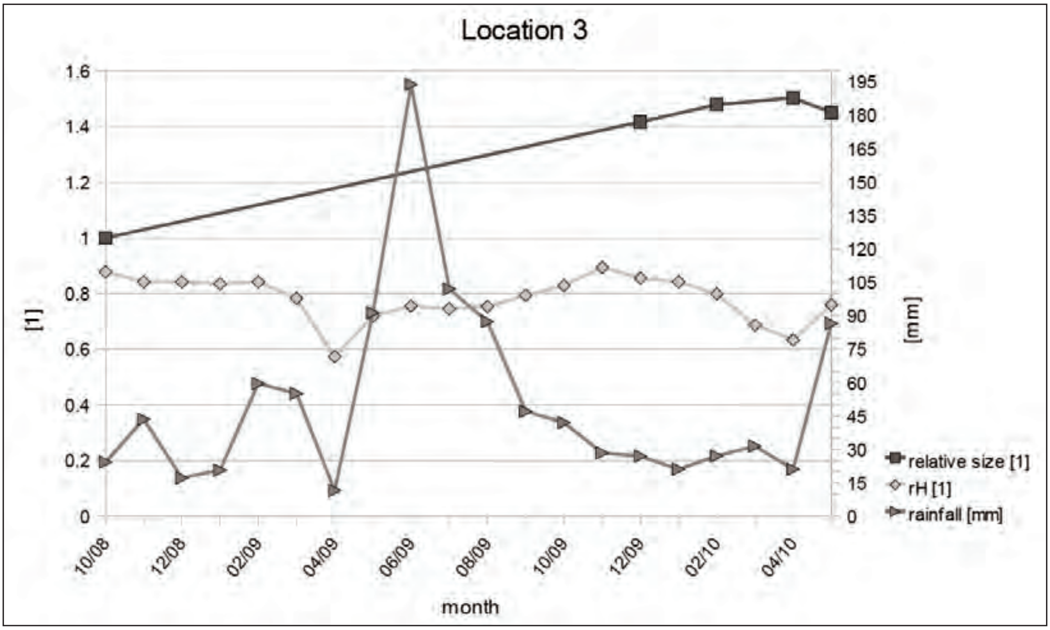

Fig. 26: Relative lichen size of *Xanthoria parietina* on location 3, relative air humidity (rH) and rainfall (average values of Linz).

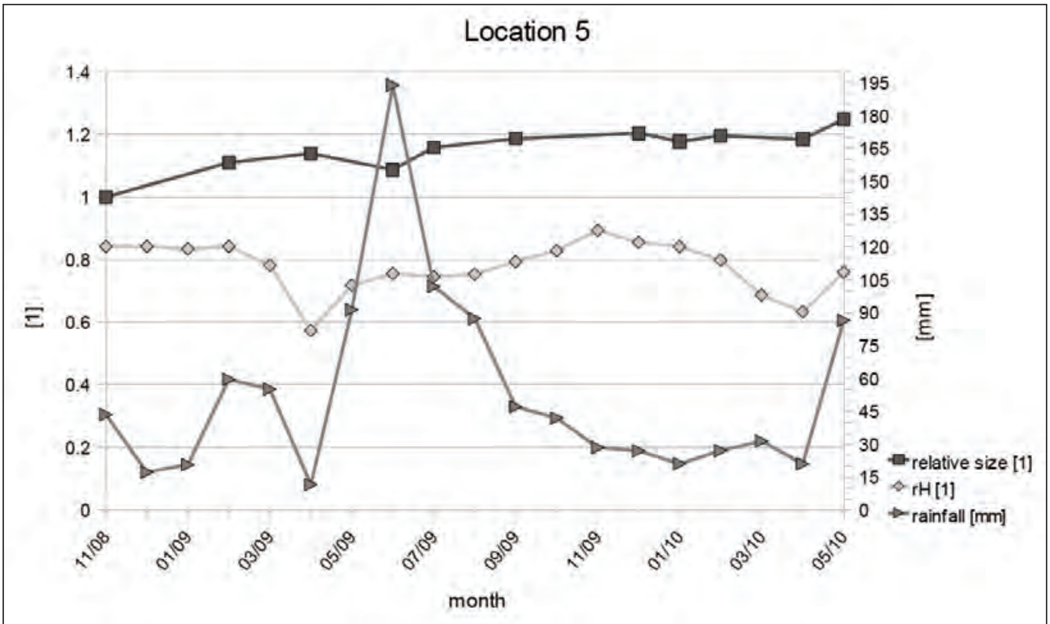

Fig. 27: Relative lichen size of *Xanthoria parietina* on location 5, relative air humidity (rH) and rainfall (average values of Linz).

area of 2,97 cm^2 (Fig. 27). This equates to a relative increase of 25 %. There were some slight decreases from April to June 2009 (-0,62 cm^2, -5 %), from December 2009 to January 2010 (-0,32 cm^2, -3 %) and from February to April 2010 (-0.14 cm^2, -1 %).

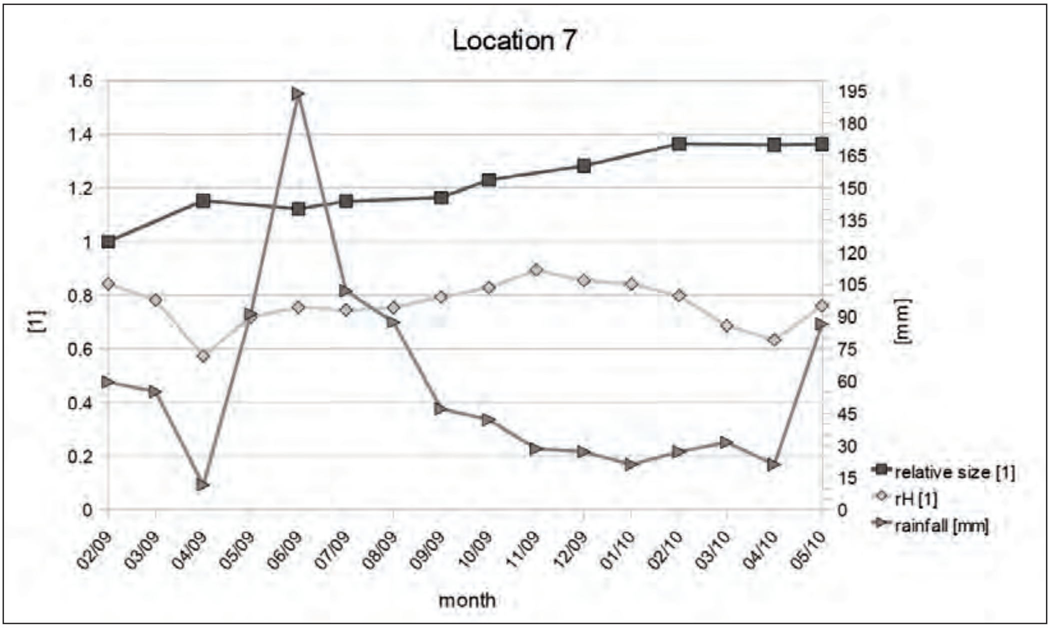

Fig. 28: Relative lichen size of *Xanthoria parietina* on location 7, relative air humidity (rH) and rainfall (average values of Linz).

From February 2009 to February 2010, a growth of 9 % was recorded (1,03 cm^2).

5.1.4 Location 7

On measurement site 7 (see Fig. 28), a total growth of 2,35 cm^2 (increase of 36 %) was recorded during the investigation period from February 2009 to May 2010. In one year (February 2009 to February 2010) *Xanthoria parietina* increases 36 % in thallus area which equates to a total growth of 2,36 cm^2. From April 2009 to June 2009 an decrease of -19 cm^2 (-3 %) occurred. During the period February 2010 to April 2010 thallus area reduced for -3 cm^2.

5.1.5 Location 8

Phaeophyscia orbicularis shows a strong and linear growth (trend line: R^2 = 0,99) during the whole investigation period. The total increase in area amounts to 0,67 cm^2 which equates to 69 % (Fig. 29). No periods of decrease have been detected. Between June and July 2009 (increase of 10 %) and between January and February 2010 (increase of 7 %) two periods of stronger growth occurred. The lichen developed very well, no thallus damages have been observed. According to the trend line, a monthly growth of 4 % can be observed.

5.1.6 Location 9

Parmelia sulcata was investigated at measurement site 9 from November 2008 until May 2010 (Fig. 30). Thallus area increased during the investigation period for 2,43 cm^2 or 42 %. In the period from February 2009 to February 2010 it increased 27 %, which is equivalent to 1,58 cm^2. From October 2009 to December 2009 a decrease of -0,86 cm^2 (-15 %) was detected.

5.1.7 Location 10

10a

In the beginning of the investigation period, *Melanohelia exasperatula* (10a) showed a

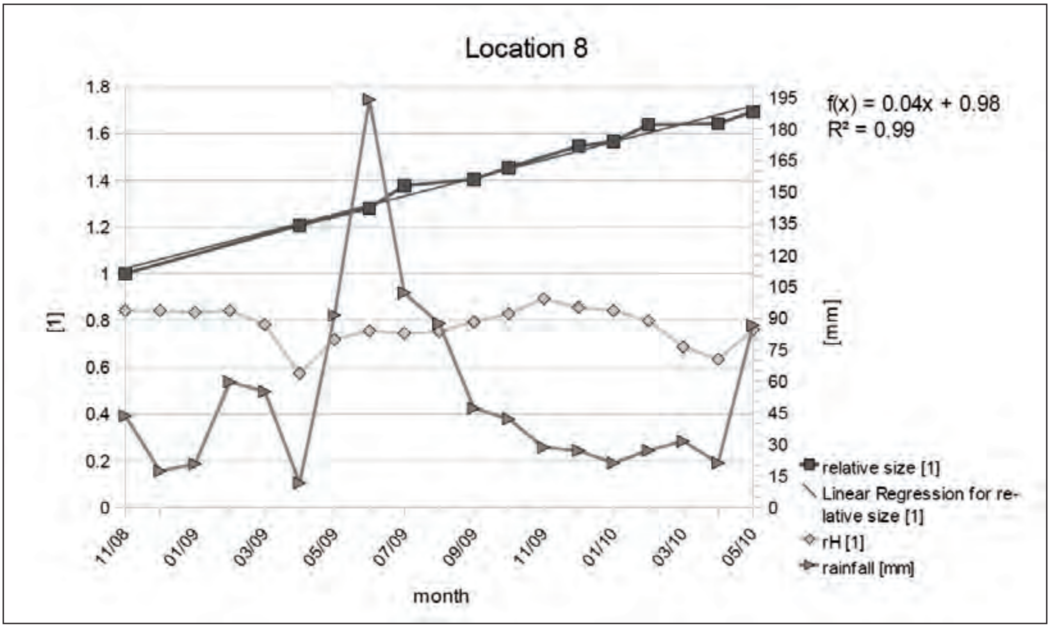

Fig. 29: Relative lichen size of *Phaeophyscia orbicularis* on location 8 with trend line and trend line equation, relative air humidity (rH) and rainfall (average values of Linz).

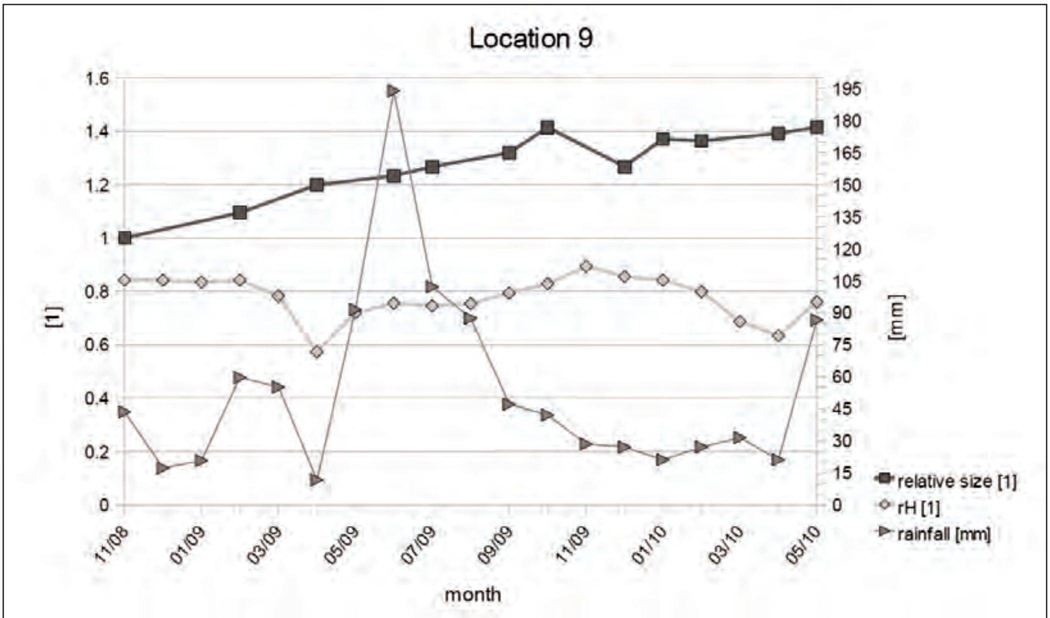

Fig. 30: Relative lichen size of *Parmelia sulcata* on location 9, relative air humidity (rH) and rainfall (average values of Linz).

slow growth. In April 2009, inner parts of the thallus started to detach. The lichen was growing until July 2009 which resulted in a total growth of 1,2 cm^2 or 7 % (November

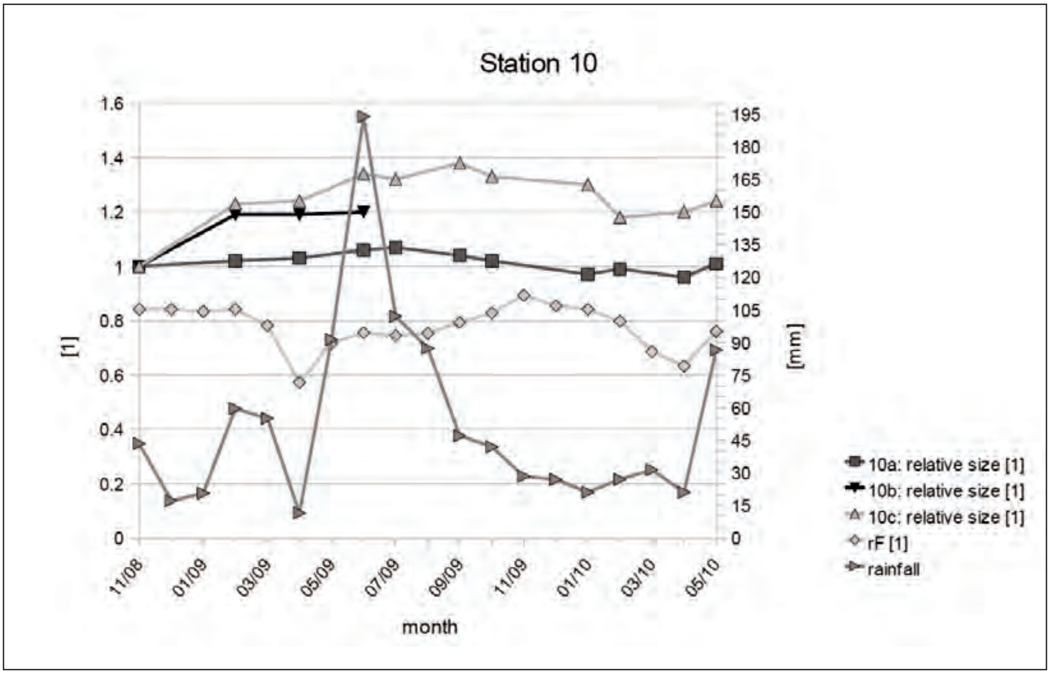

Fig. 31: Relative lichen size of location 10 (10a: *Melanohelia exasperatula,* 10b: *Melanohelia sp.*, 10c: *Parmelia sulcata*), relative air humidity (rH) and rainfall (average values of Linz).

2008 to July 2009). Then the lichen area started to decrease. Additionally, in October 2009, parts of the outer thallus were missing. From April to May 2010, again a slight growth was observed as can be seen in Fig. 31.

10b

Melanohelia sp. performed very well in the beginning and gained 2,27 cm^2 (19 %) in thallus area (Fig. 31). Then it started to decrease until measurement was not possible any more because of the substantial damage.

10c

From November 2008 to September 2009, *Parmelia sulcata* showed the best performance (compare Fig. 31). In this period it increased in 3,96 cm^2 or 38 %. Then, like in 10b, thallus area began to decrease. From February 2010 to May 2010 it started to grow again. Overall, a total growth of 24 % (2,5 cm^2) was observed during the whole investigation period. During one year (February 2009 - February 2010) *P. sulcata* decreased by -0,58 cm^2 (-6 %).

5.1.8 Location 12

Xanthoria parietina showed a strong growth on location 12. During the whole investigation period it´s thallus size increased by 1,92 cm^2 or 129 % (Fig. 32). From February 2009 to February 2010 it gained 1,46 cm^2 (98 %) in area. In the beginning of the investigation period, from November 2008 to July 2009, *Xanthoria parietina* increased 38 cm^2 which equates to 25 %. The growth rate therefore is 3 % per month in the first period (Fig. 33). The strongest growth took place from July 2009 to May 2010 with a total increase of 1,54 cm^2 (103 %). Compared to Fig. 33, in this time the growth-rate is 11 % per month. Fig. 34 indicates that the growth of *Xanthoria parietina* on location 12 is nearly exponential.

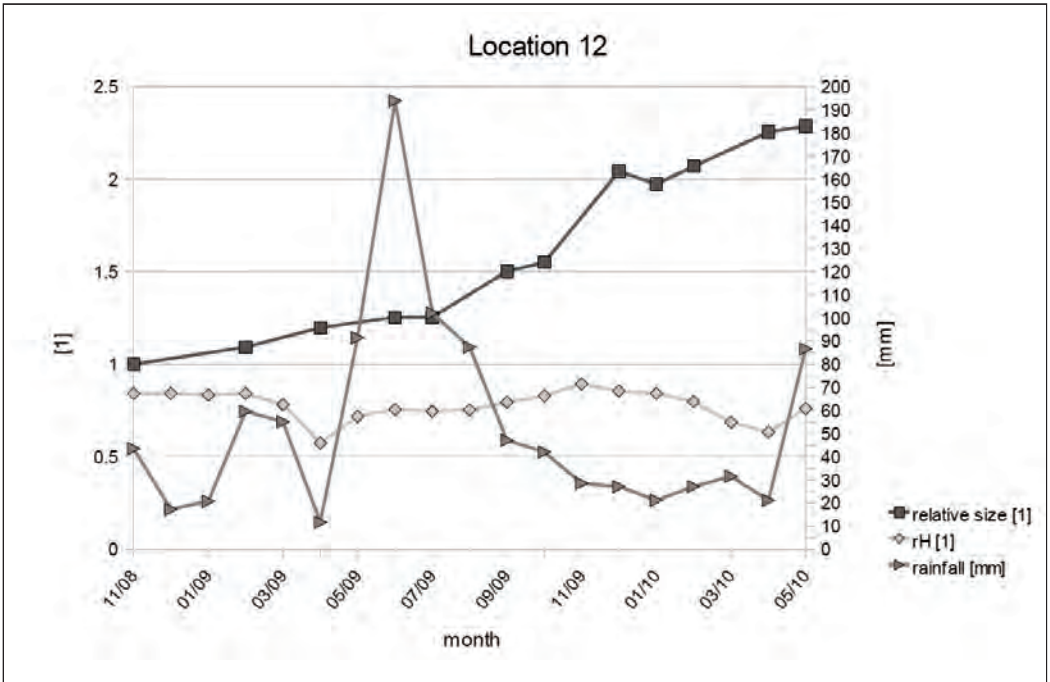

Fig. 32: Relative lichen size of location 12, relative air humidity (rH) and rainfall (average values of Linz).

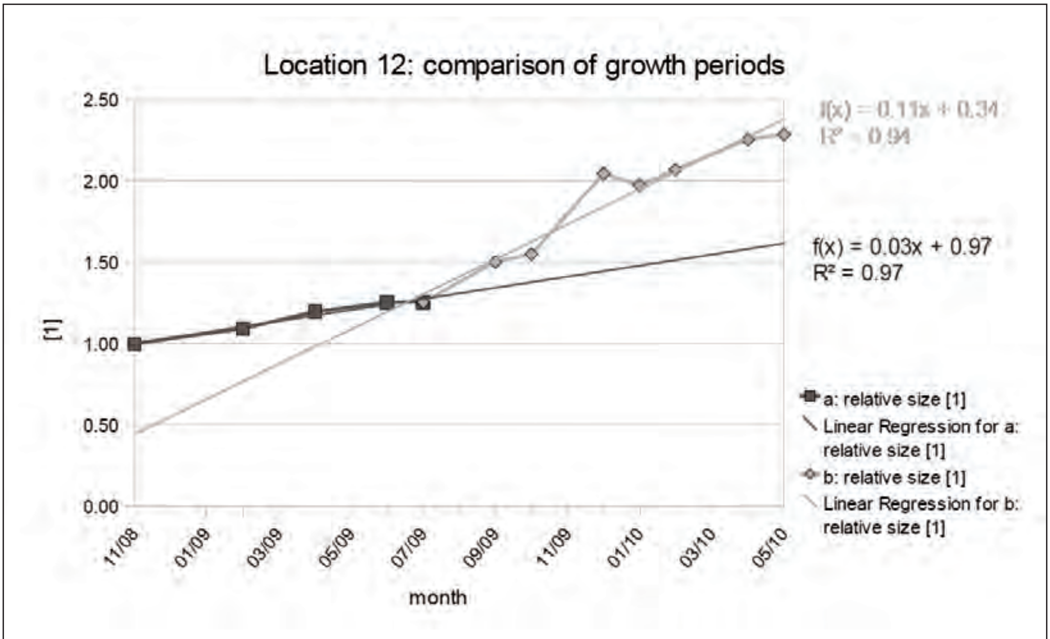

Fig. 33: Comparison of growth periods of *Xanthoria parietina* on Location 12. a: November 2008-July 2009 (Trend line equation: f(x) = 0,03x + 0,97, stability index R^2 = 0,94), b: July 2009-May 2010 (Trend line equation: f(x) = 0,11x + 0,34, stability index R^2 = 0,97).

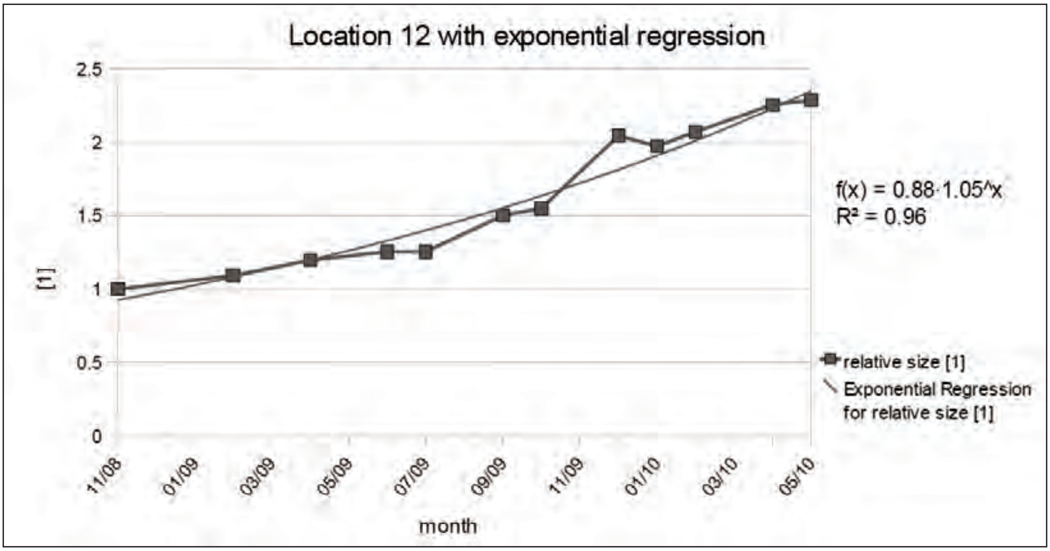

Fig. 34: Exponential regression, applied to the relative size of *Xanthoria parietina* on Location 12.

5.1.9 Location 13

13a

Xanthoria parietina shows a very similar performance to the second lichen on this measurement site though it had a stronger growth rate in the beginning (Fig. 35). During the whole investigation period the total gain in thallus area was 5,04 cm^2 which equates to 69 % increase. In the period of one year

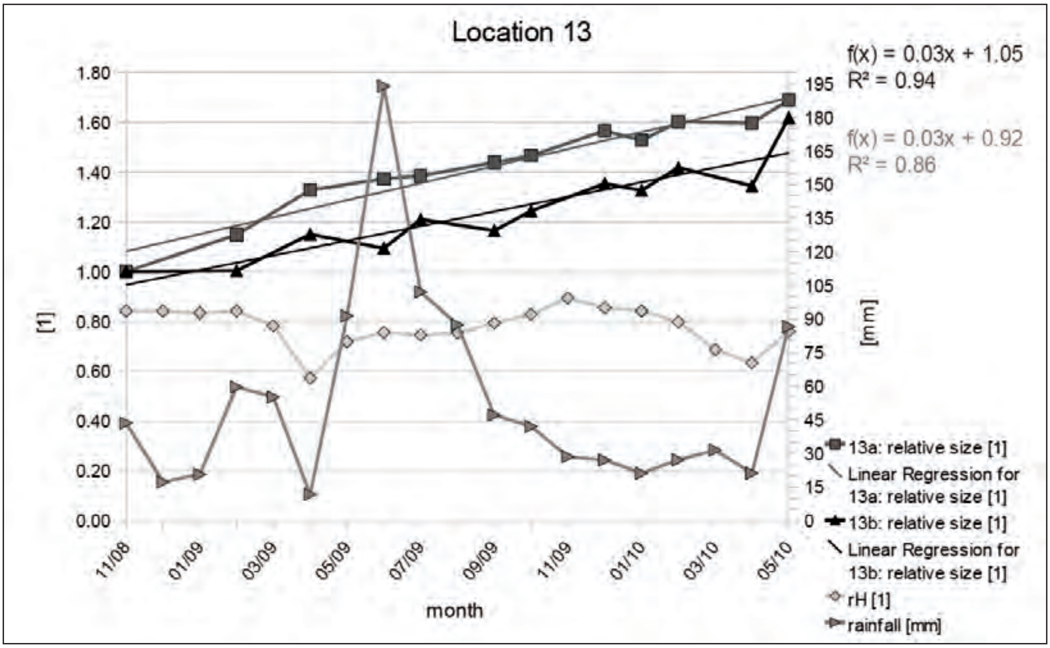

Fig. 35: Relative lichen size on location 13 (13a: *Xanthoria parietina*, 13b: *Phaeophyscia orbicularis*) with trend line and trend line equation, relative air humidity (rH) and rainfall (average values of Linz).

(February 2009 - February 2010) it increased 3,06 cm² or 42 %. From December 2009 to January 2010 a slight decrease occurred, which was compensated by an increase from January to February. Then growth stagnated until April.

13b

Phaeophyscia orbicularis and *Xanthoria parietina* on location 13 show a quite similar growth behaviour which is confirmed by the correlation coefficient 0,91. The trend lines for both lichens show the same gradient of 3 % per month, whereas the growth of *Xanthoria parietina* is rather linear than the one of *Phaeophyscia orbicularis* (see Fig. 35). Over the whole investigation period, a total growth of 2,2 cm² has been observed (relative: 62 %). During one year (February 2009 - February 2010) *Phaeophyscia orbicularis* showed an increase of 1,47 cm² or 41 %.

5.1.10 Location 14

14a

On measurement site 14, two individuals of *Xanthoria parietina* have been investigated (Fig. 36 and 37). Both lichens show a similar growth behaviour, but 14a grows more linear than 14b. According to the trend line, a monthly growth rate of 2 % can be assumed. During the investigation period from November 2008 to May 2010, a total growth of 4,19 cm² has been observed. This equates to a relative growth of 33 %. In one year, from February 2009 to February 2010, it gained 3,54 cm² (28 %) in thallus size. In the beginning, a slight decrease of 1 % was observed (November 2008 to January 2009), followed by a growth period from January to June 2009 (+2,78 cm², 22 %). From July to September 2009 size decreased again by -0,8 cm, followed by a growing period until the end of the investigation time.

14b

14b has a higher fluctuation which is indicated by a lower stability index (stability index of the trend line: $R^2 = 0,88$) according to the equation of the trend line. Assuming a linear growth performance, *Xanthoria parietina* has a monthly growth rate of 2 % on this location. The first period of area increase was from November 2008 to April

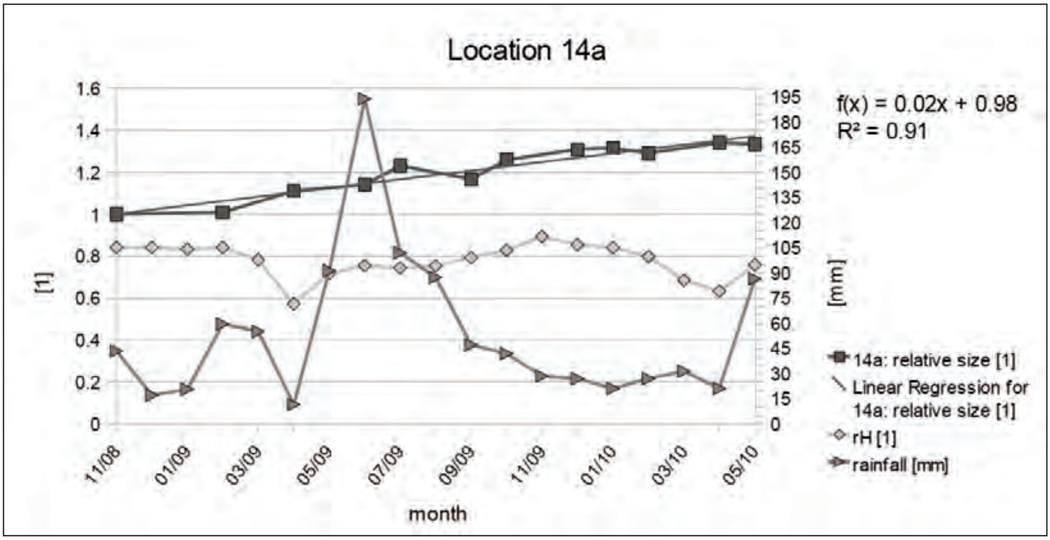

Fig. 36: Relative lichen size of *Xanthoria parietina* on location 14a with trend line and trend line equation, relative air humidity (rH) and rainfall (average values of Linz).

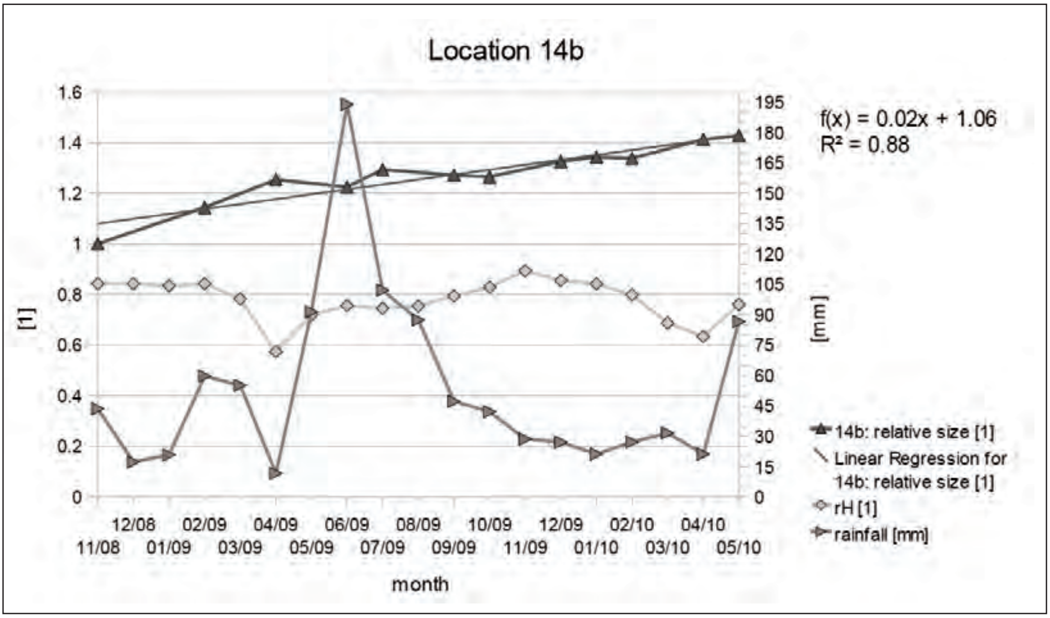

Fig. 37: Relative lichen size of location 14 (a, b: both *Xanthoria parietina*) with trend line and trend line equation, relative air humidity (rH) and rainfall (average values of Linz).

2009 with a gain of 25 % (0,86 cm²). In the following, growth was slightly fluctuating.

5.1.11 Location 15

15a

Xanthoria parietina on location 15a was investigated from November 2008 to October 2010. In this period growth was quite irregular. In the beginning, from November 2008 to February 2009, a decrease of 15 % occurred (-0,32 cm²). A linear growth period followed from February to June 2009 (+0,39 cm², +18 %). From June 2009 to July a stronger gain of thallus area was observed (+0,39 cm², +18 %). Then growth rate slows down again until the end of the investigation period. During the total investigation time, a growth of 0,74 cm² was observed, which equates to a area gain of 34 % (see Fig. 38).

15b

Measurement of the second individual of *Xanthoria parietina* started in February 2009 and was continued until October 2009. In this period, a total growth of 0,84 cm² or 33 % has been detected. During the period, when both lichens were measured, they showed the same growth performance. Anyway, from July 2009 on, the thallus area size decreased.

5.1.12 Location 16

Xanthoria parietina has been observed on location 16 from February 2009 to May 2010. In this period it show a quite irregular growth behaviour. A total growth of 0,42 cm² was detected which is equally to a gain of 45 %. In one year (February 2009 to January 2010) a growth of 0,28 cm² or 30 % occurred. From February to April 2009, thallus area increased at 0,2 cm² (21 %). Then the growth curve flattens, followed by a decrease from June to September 2009 (-0,14 cm², -15 %). In the following the lichen growths quite constant (Fig. 39).

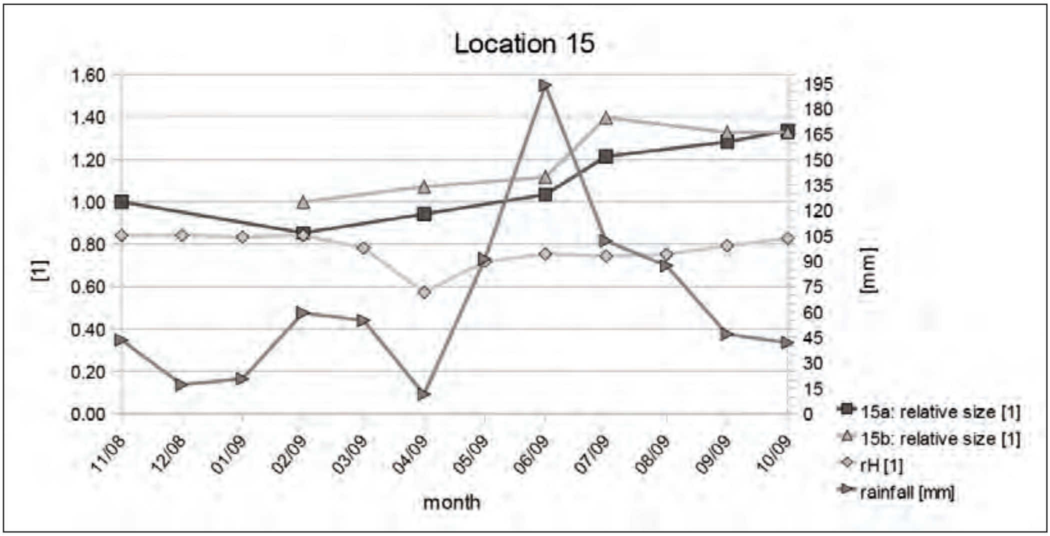

Fig. 38: Relative lichen size on location 15, relative air humidity (rH) and rainfall (average values of Linz).

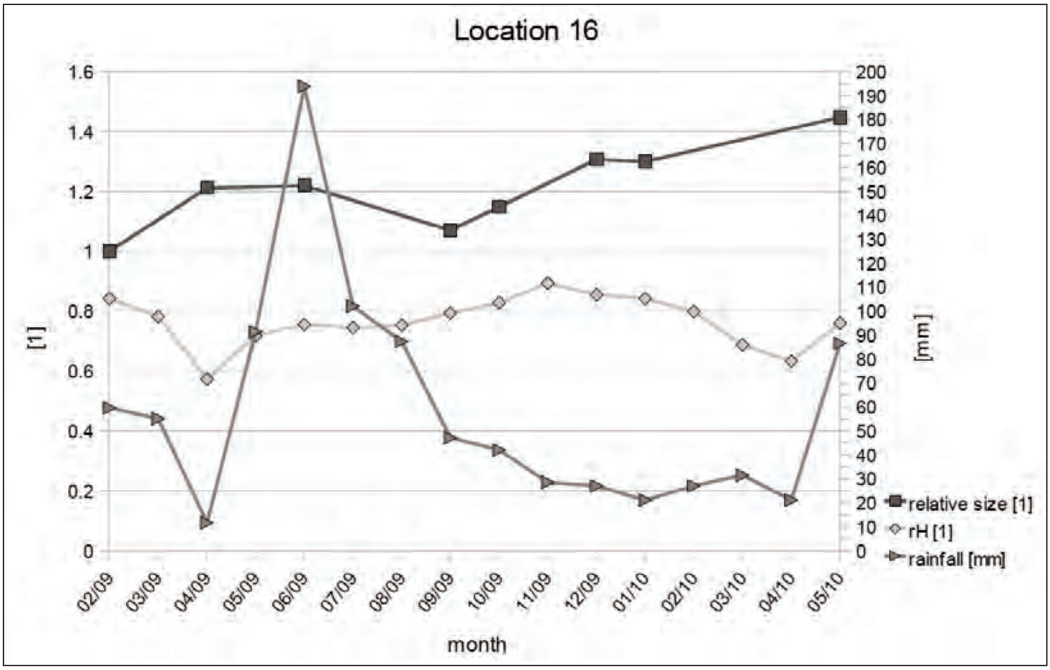

Fig. 39: Relative lichen size of *Xanthoria parietina* on location 16, relative air humidity (rH) and rainfall (average values of Linz).

5.1.13 Location 17

17a

In location 17a, *Melanohelia exasperatula* has been observed. Measurement was only possible from February 2009 to June 2009, because the thallus was damaged after this time. In this short period, the thallus gained 0,51 cm^2 or 24 %.

17b

Xanthoria parietina on measurement station 17b showed a continuous growth during the whole period and gained 1,88 cm^2, which equates to 109 %. From February 2009 to January 2010, it increased 1,53 cm^2 or 88 % in thallus area.

17c

Phaeophyscia orbicularis on station 17b showed a quite similar behaviour like *Xanthoria parietina* (17b). From December 2009 to January 2010 a slight decrease of thallus area occurred (Fig. 40).

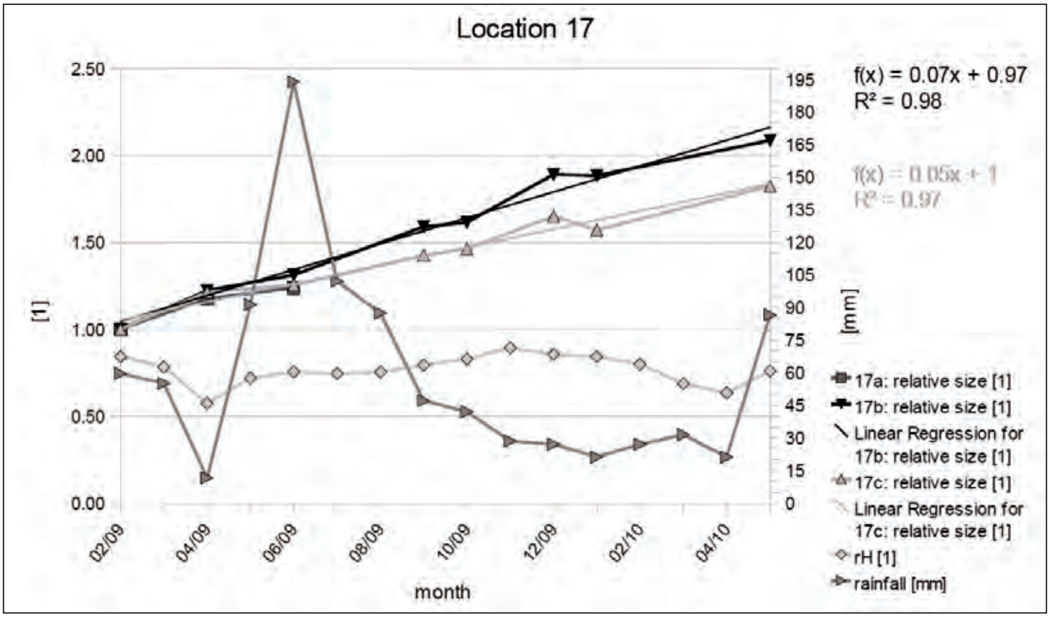

Fig. 40: Relative lichen size on location 17 (17a: *Melanohelia exasperatula*, 17b: *Xanthoria parientina*, 17c: *Phaeophyscia orbicularis*), relative air humidity (rH) and rainfall (average values of Linz).

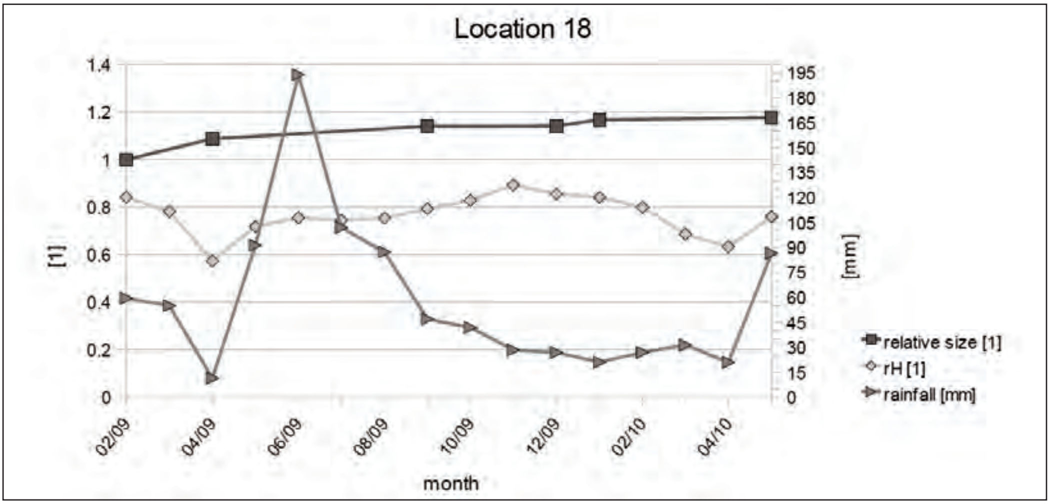

Fig. 41: Relative lichen size of *Phaeophyscia orbicularis* on location 18, relative air humidity (rH) and rainfall (average values of Linz).

5.1.14 Location 18

Phaeophyscia orbicularis showed a total growth of 0,25 cm^2 or 18 %. Growth performance was quite regular (Fig. 41).

5.1.15 Location 19

Melanohelia exasperatula was observed on station 19 from February 2009 to May 2010. In this period, a total growth of 2,41 cm^2 (increase of 28 %) was observed. From February to April 2009, area increased at 0,95 cm^2 or 11 %. Then growth stagnated until June 09. From June 2009 to January 2010, thallus area increased by 1,61 cm^2, which equates 18 %. In the following, thallus decreased again slightly (Fig. 42).

5.1.16 Location 20

The Lichen size of *Xanthoria parietina* increased during the whole investigation period at 0,14 cm^2 which equates to 47 % thallus area. In one year (April 2009 to April 2010) an area gain of 0,08 cm^2 or 26 % was observed. From February 2010 to April 2010 a decrease of -0,02 cm^2 (-8 %) occurred (Fig. 43).

5.1.17 Location 21

In the beginning of the investigation period, *Phaeophyscia orbicularis* showed a slight growth until June 2009. Then thallus size decreased by -0,31 cm^2 (-10 %). Growth curve decreased then until January 2010, followed by a short increase. From April 2010 until the end of the investigation period, thallus size decreased again. During the whole time of investigation, a total growth of 0,03 cm^2 or 1 % was measured (Fig. 44).

5.1.18 Location 22

The growth performance of *Parmelia sulcata* on location 22 was not constant. During the whole investigation period a decrease of -0,09 cm^2 was observed which equates to -12 %. In the time span of one year (December 2008 to December 2009) a decrease of -0,03 cm^2 or -4 % was detected (Fig. 45).

5.1.19 Location 23

23a

Xanthoria parietina on location 23a showed a total growth of 0,89 cm^2 during the whole

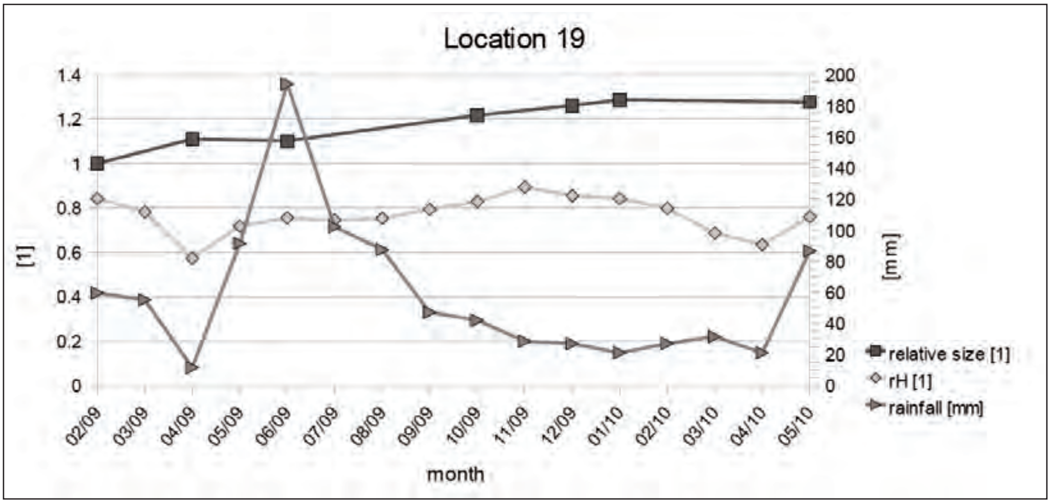

Fig. 42: Relative lichen size of *Melanohelia exasperatula* on location 19, relative air humidity (rH) and rainfall (average values of Linz).

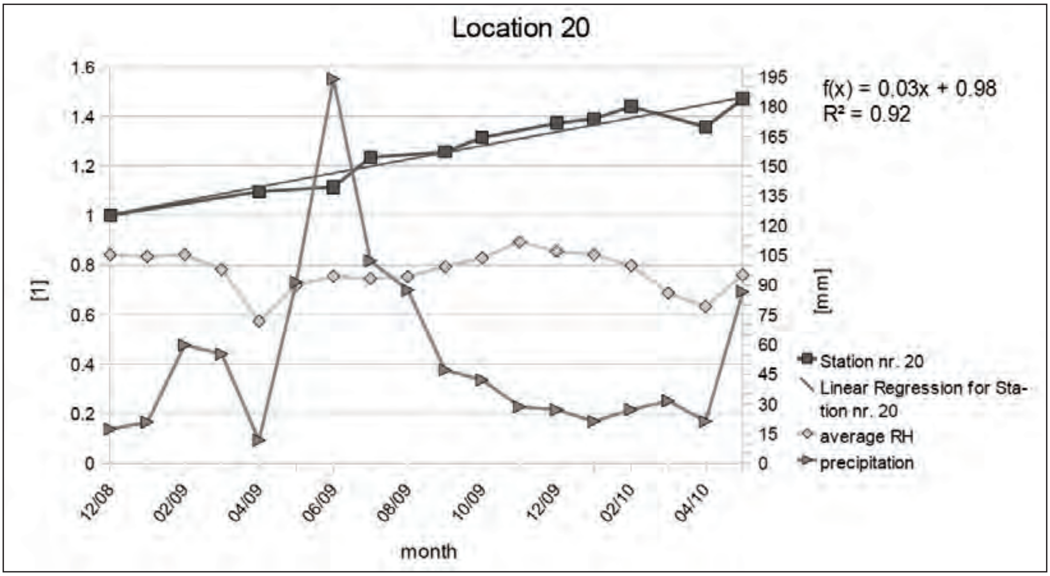

Fig. 43: Relative lichen size of *Xanthoria parietina* on location 20, relative air humidity (rH) and rainfall (average values of Linz).

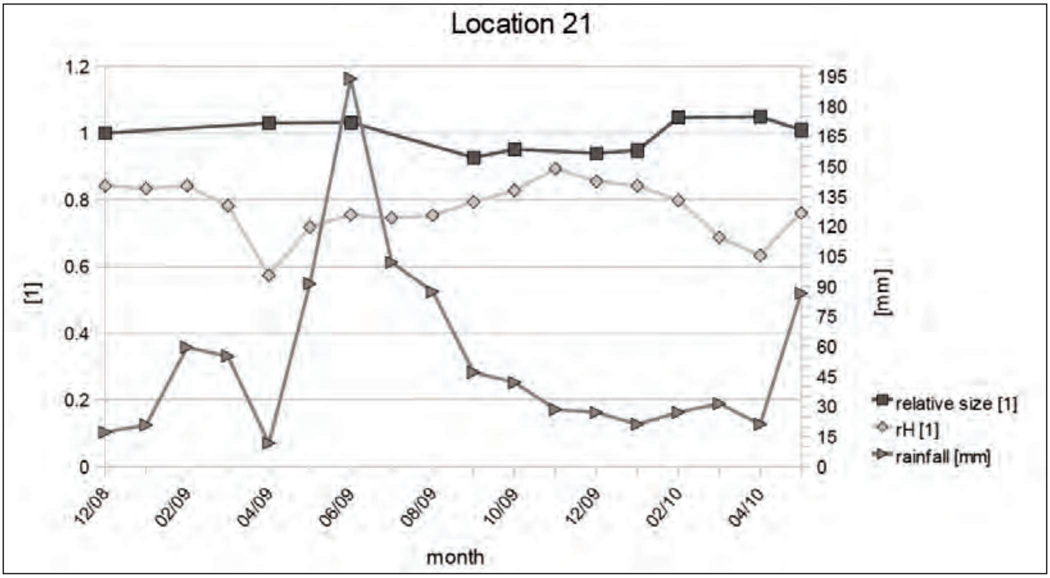

Fig. 44: Relative lichen size of *Phaeophyscia orbicularis* on location 21, relative air humidity (rH) and rainfall (average values of Linz).

investigation period (Fig. 46). In one year (April 2009 to April 2010) an increase of 0,53 cm^2 (14 %) was observed. The trend line equation indicates a monthly growth of 1 %. Linear growth is assumed by the stability index of 0,93.

23b

Parmelia sulcata shows a slight growth during the investigation period from December 2008 to May 2010 with a total increase of 0,76 cm^2 (13 %). In one year (April 2009 to

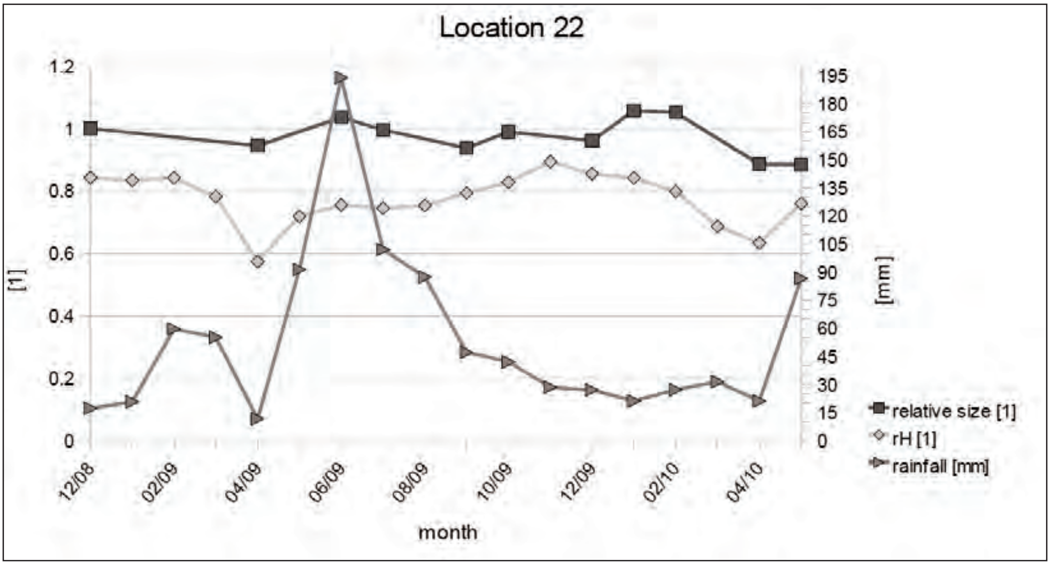

Fig. 45: Relative lichen size of location 22, relative air humidity (rH) and rainfall (average values of Linz).

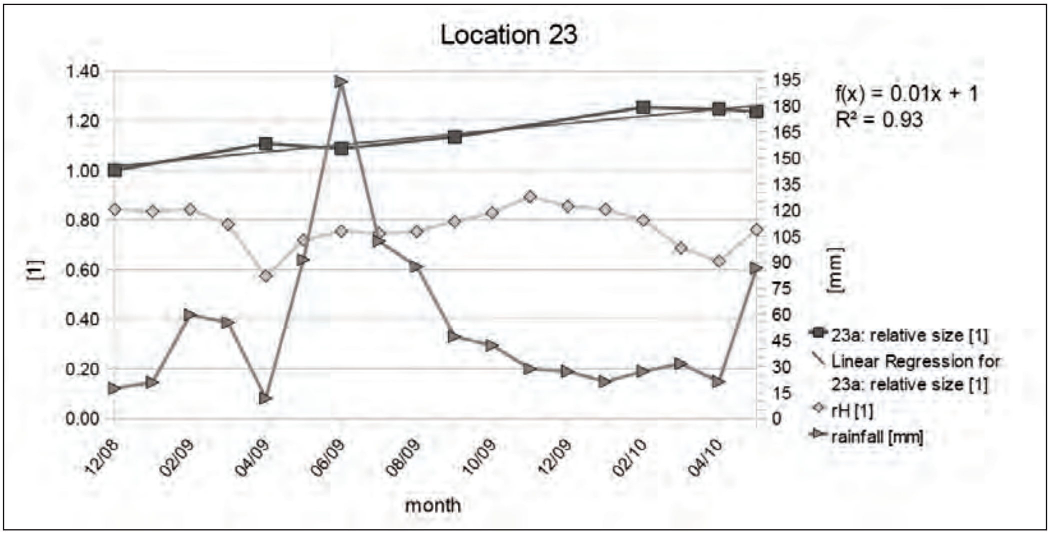

Fig. 46: Relative lichen size of *Xanthoria parietina* on location 23a, relative air humidity (rH) and rainfall (average values of Linz).

April 2010) the lichen increased 0,83 cm^2 or 15 % thallus area. From December 2009 to January 2010 and from April 2010 to May 2010 slight decrease occurred (Fig. 47).

23c

The thallus of *Parmelia sucata* on Location 23 showed a total growth of 8,21 cm^2 which equals to 38 %. In the beginning there was only a slight growth from December 2008 to April 2009. In the following growth increased until October 2009. From October to December 2009 a decrease of -1,74 cm^2 occurred (-8 %). After that thallus size increased again until the end of the investigation period. According to the period of one year, a growth of 7,76 cm^2 or 36 % was detected from April 2009 to April 2010 (Fig. 48).

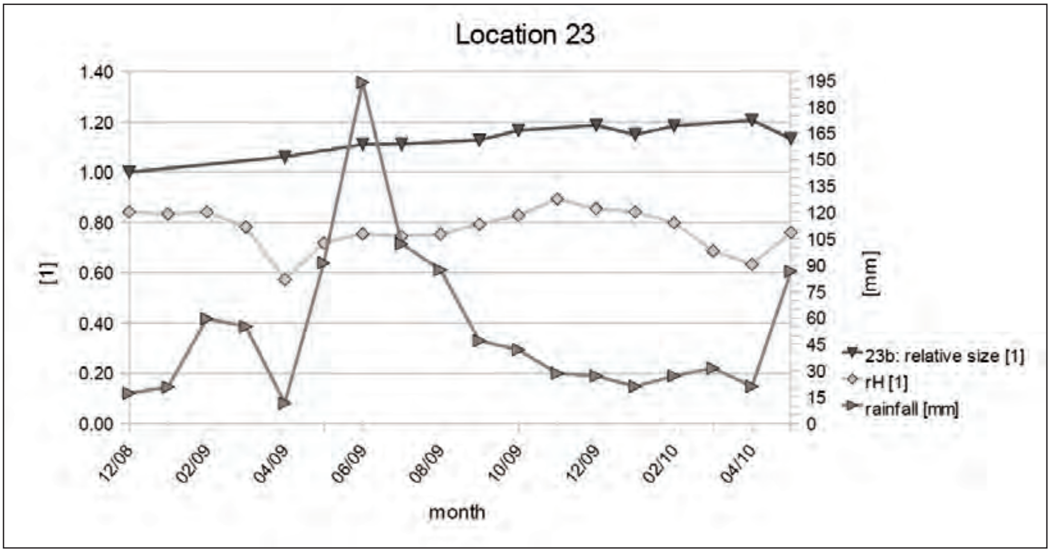

Fig. 47: Relative lichen size of *Parmelia sulcata* on location 23b, relative air humidity (rH) and rainfall (average values of Linz).

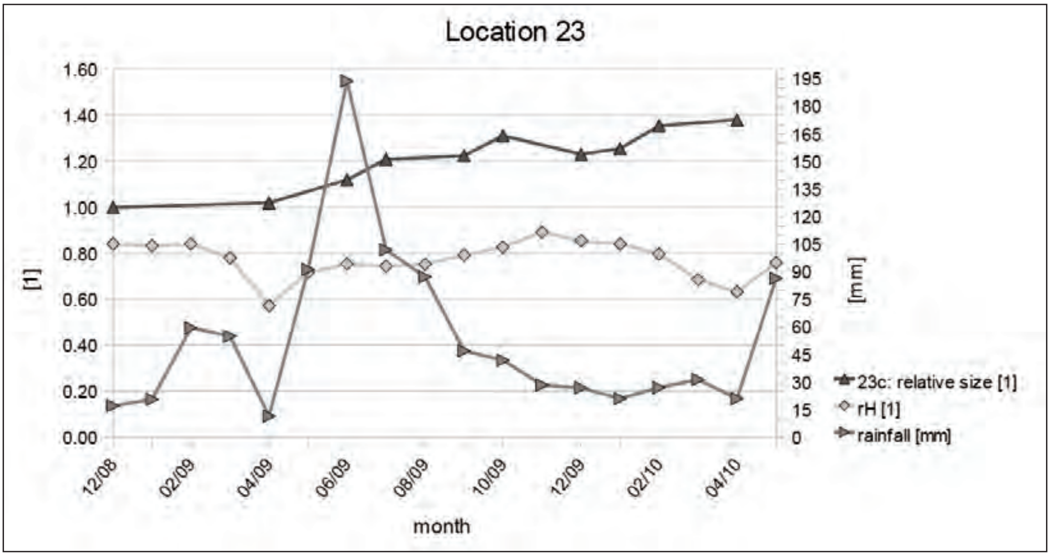

Fig. 48: Relative lichen size of *Parmelia sulcata* on location 23c, relative air humidity (rH) and rainfall (average values of Linz).

5.1.20 Location 24

24a

The growth rate of *Phaeophyscia orbicularis* was quite linear, which is also supported by the stability index of 0,96. The trend line equation indicates a monthly growth of 2 % although between February and December 2009, measurement was not possible. During the whole investigation period, a total growth of 0,73 cm^2 or 34 % has been observed. In the period of one year (February 2009 to February 2010) the lichen gained 0,53 cm^2 in area which equates to 25 % (Fig. 49).

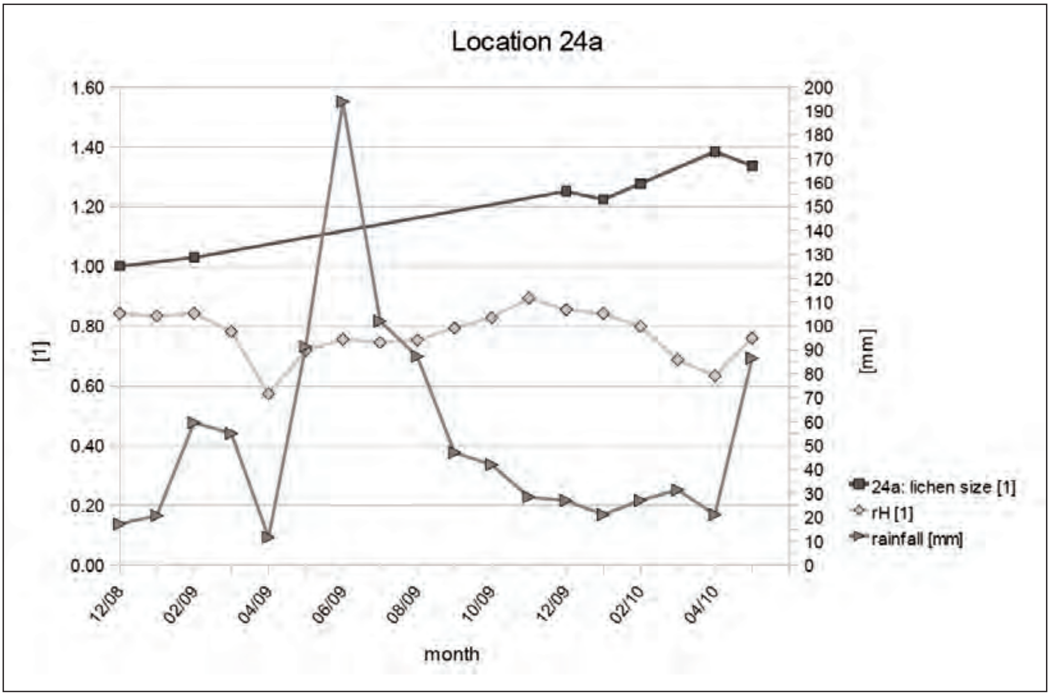

Fig. 49: Relative lichen size of *Phaeophyscia orbicularis* on location 24, relative air humidity (rH) and rainfall (average values of Linz).

24b

Growth performance of *Parmelina tiliacea* followed approximately an exponential curve as shown by the regression equation in Fig. 50. During the whole investigation period, a total growth of 2,46 cm^2 (110 %) has been observed. From January 2009 to January 2010, an increase of 1,95 cm^2 or 88 % was detected. No periods of thallus decrease occurred. From February 2010 until the end of the investigation period, growth curve flattens slightly.

24c

Phaeophyscia orbicularis showed a nearly linear growth during the investigation period. From December 2008 to May 2010 a total growth of 1,22 cm^2 was observed which equates to 46 %. During the period in the year from February 2009 to February 2010, an increase of 0,97 cm^2 or 36 % was detected (Fig. 51).

24e

During the investigation period, *Xanthoria parietina* showed a total growth of 1,74 cm^2 (76 %). In one year (February 2009 to February 2010) an increase of 1,26 cm^2, which equates to 55 % was observed. According to the regression equation, a linear growth can be assumed (Fig. 52).

5.1.21 Location 25

25a

During the investigation period from December 2008 to May 2010, thallus size of *Xanthoria parietina* increased by 0,32 cm^2 (19 %). In the one year period from February 2009 to February 2010 thallus area gained 0,1 cm^2 or 6 %. From December 2008 to July 2009 a continuous growth was observed, followed by a decrease until December 2009. A short increase until January 2010 was compensated by another decrease until

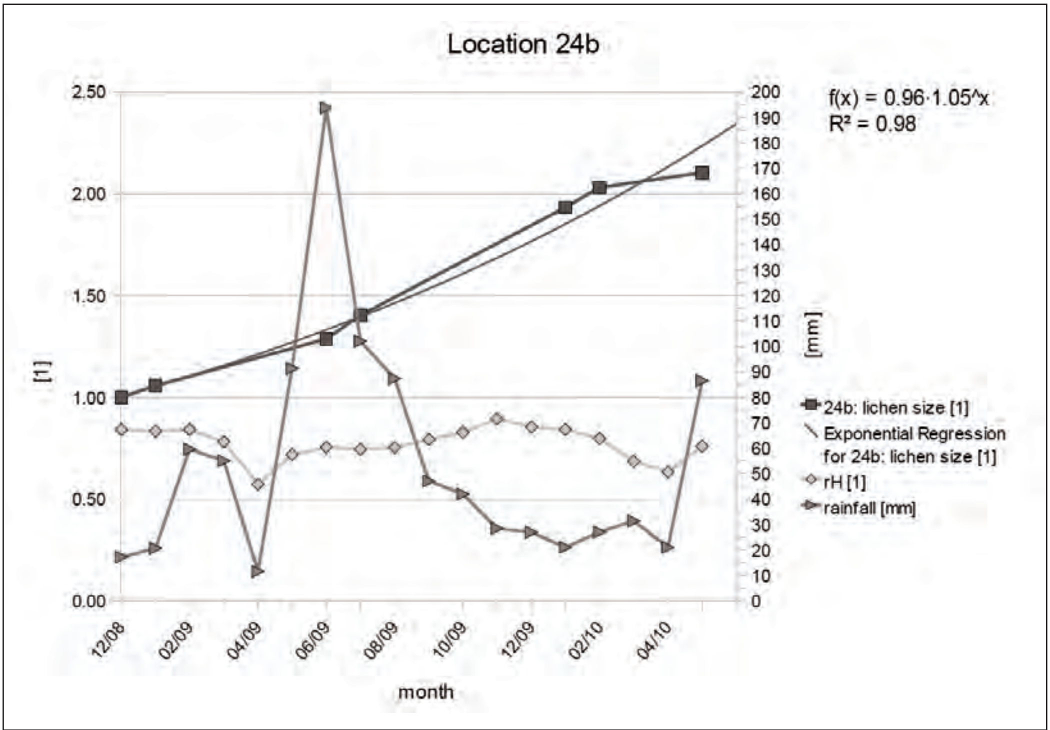

Fig. 50: Relative lichen size of *Parmelina tiliacea* on location 24b, relative air humidity (rH) and rainfall (average values of Linz).

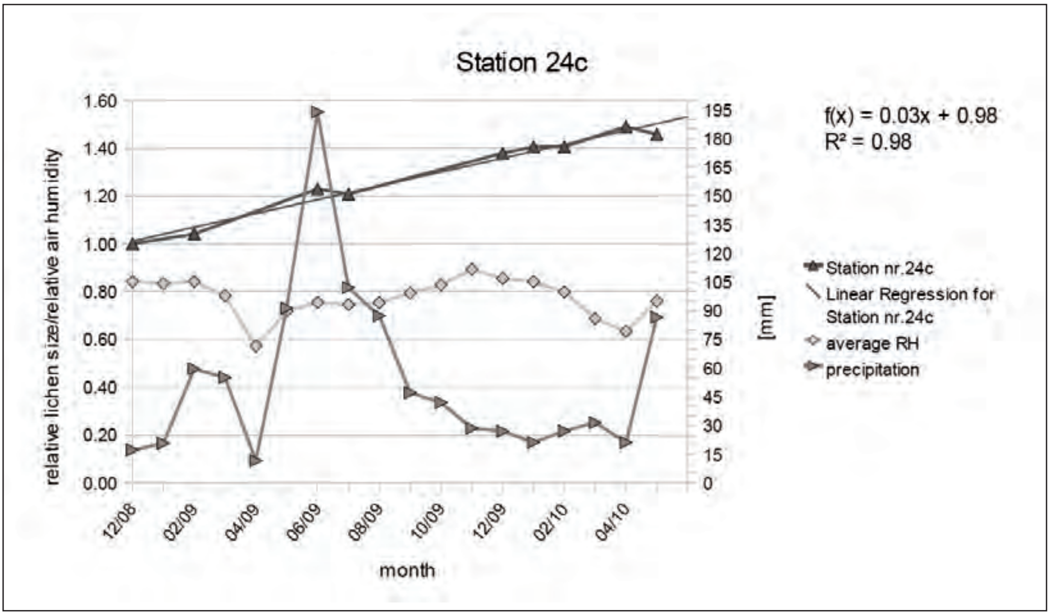

Fig. 51: Relative lichen size of *Phaeophyscia orbicularis* on location 24c, relative air humidity (rH) and rainfall (average values of Linz).

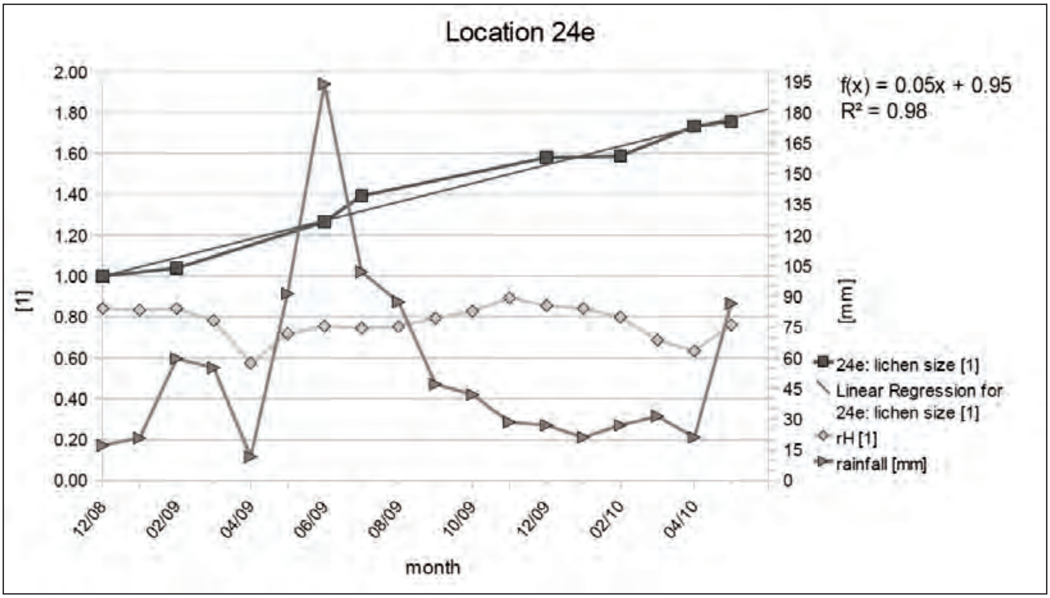

Fig. 52: Relative lichen size of *Xanthoria parietina* on location 24e, relative air humidity (rH) and rainfall (average values of Linz).

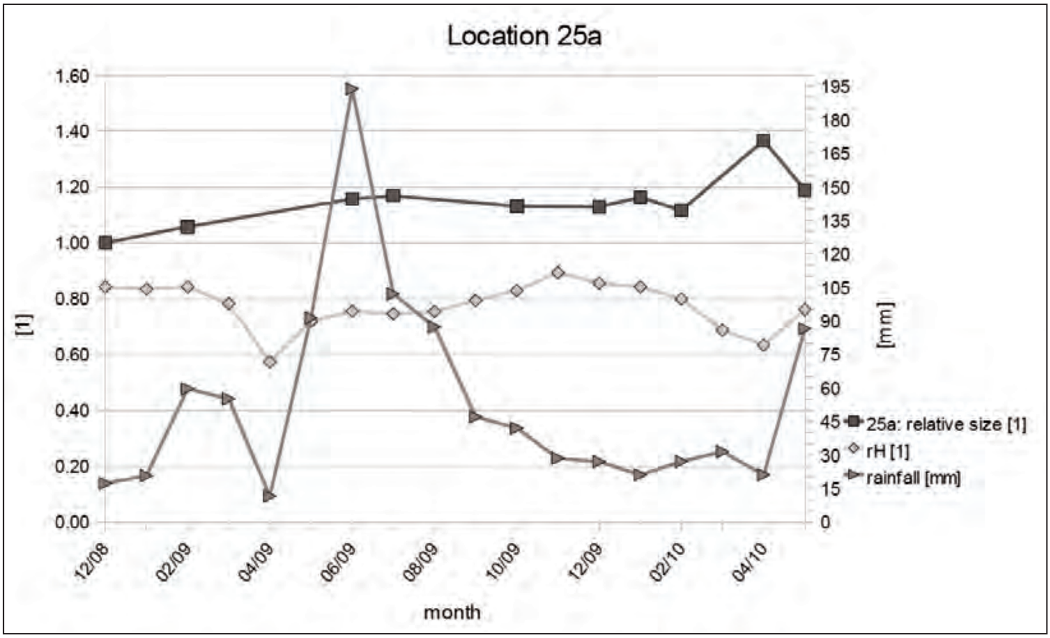

Fig. 53: Relative lichen size of *Xanthoria parietina* on location 25a, relative air humidity (rH) and rainfall (average values of Linz).

February. From February to April a strong increase occurred. In the following, thallus size again decreased (Fig. 53).

25b

On location 25b, an individual of *Parmelia sulcata* has been observed. During the whole

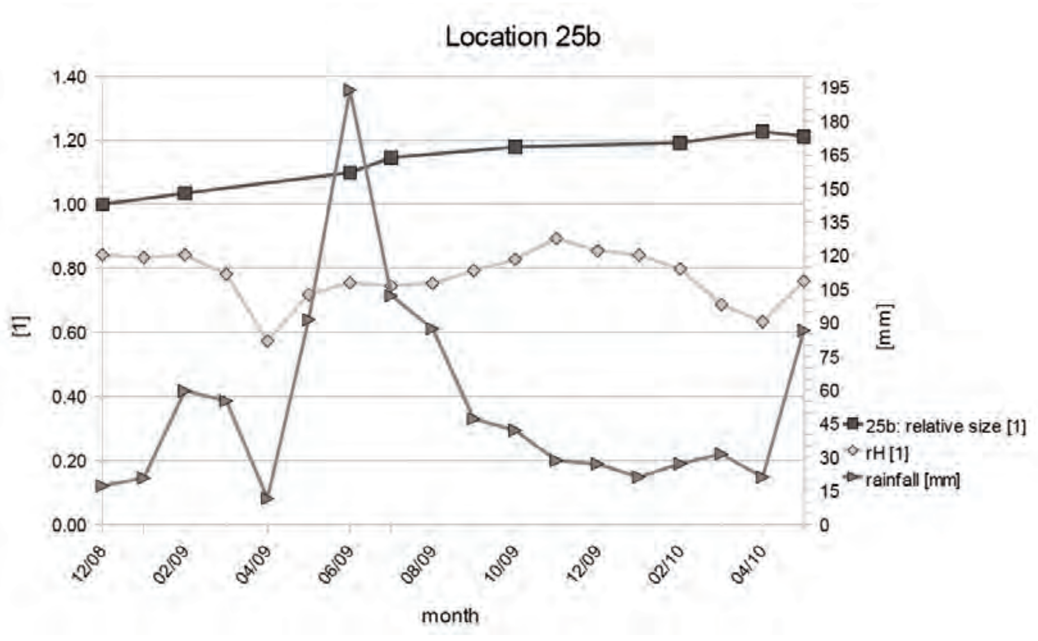

Fig. 54: Relative lichen size of *Parmelia sulcata* on location 25b, relative air humidity (rH) and rainfall (average values of Linz).

investigation period, a growth of 0,29 cm^2 or 21 % was detected. From February 2009 to February 2010 a gain of thallus area by 0,22 cm^2 was observed (16 %). There have been no periods of thallus decrease. *Parmelia sulcata* showed a quite constant growth performance (Fig. 54).

25c

Parmelia sulcata on location 25c increased 0,3 cm^2 or 20 % during the whole investigation period. From February 2009 to February 2010, a gain in thallus area of 0,26 cm^2 (18 %) was detected. In the beginning (December 2008 to June 2009), the thallus area increased slightly, followed by a period of stronger increase. From July 2009 until the end of the investigation period, thallus size decreased at -0,01 cm^2 or 1 % (Fig. 55).

25d

This *Parmelia sulcata* individual showed a quite linear growth behaviour during the investigation period. A monthly growth rate of 2 % can be assumed according to the trend line equation. From December 2008 to May 2009, a total growth of 1,72 cm^2 or 36 % was observed. During the time span of one year, *Parmelia sulcata* gained 1,32 cm^2 in thallus area (28 %). In the beginning a strong growth occurred, followed by a long period of lower growth intensity. At the end of the investigation period, a slight decrease occurred (Fig. 56).

25e

Phaeophyscia orbicularis showed a total growth of 0,61 cm^2 which equates to a relative gain in thallus area of 28 %. In the time span of one year (February 2009 to February 2010), an increase of 0,55 cm^2 or 25 % has been observed. During the investigation period, growth was quite changeable. After a first period of growth, from July to October 2009, a decrease occurred. In the following, thallus area increased again until January 2010. From January to February, again, a

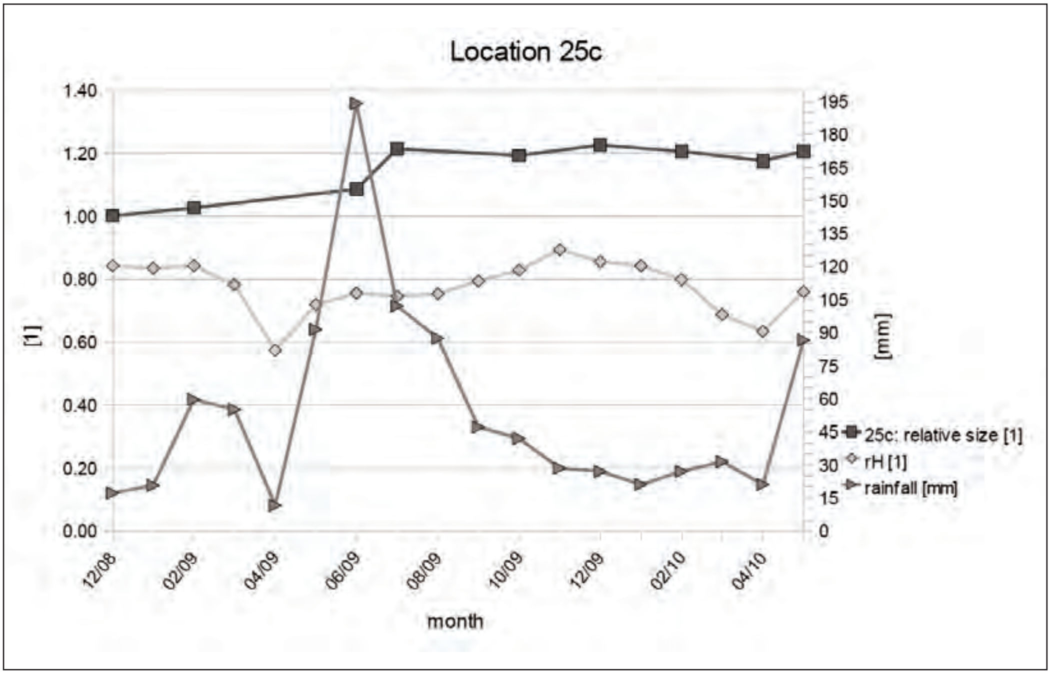

Fig. 55: Relative lichen size of *Parmelia sulcata* on location 25c, relative air humidity (rH) and rainfall (average values of Linz).

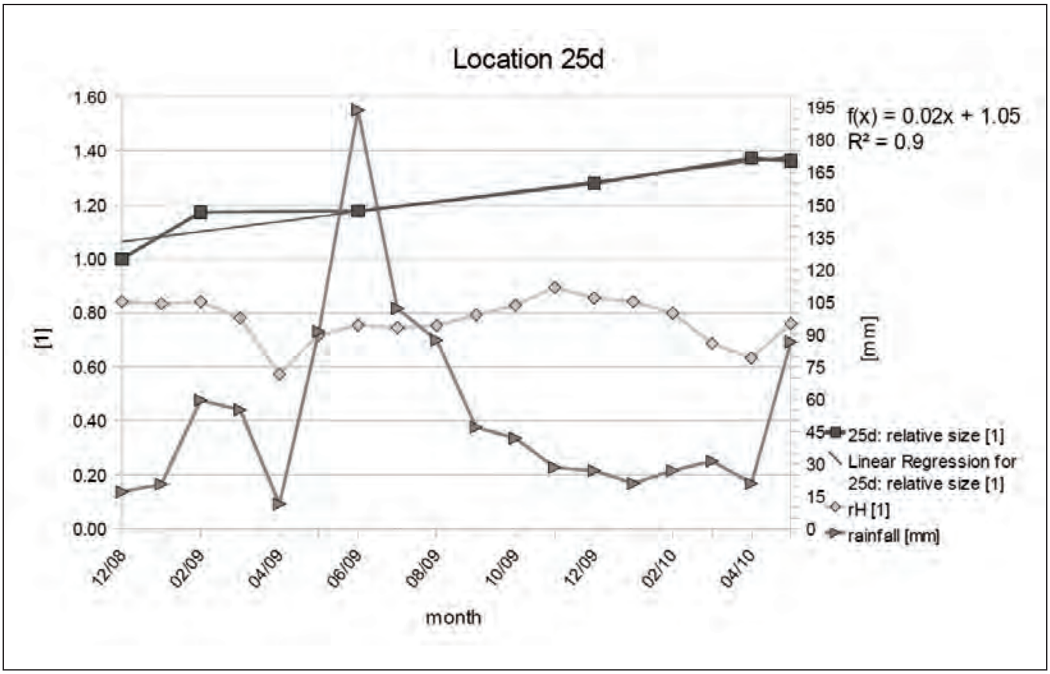

Fig. 56: Relative lichen size of *Parmelia sulcata* on location 25d, relative air humidity (rH) and rainfall (average values of Linz).

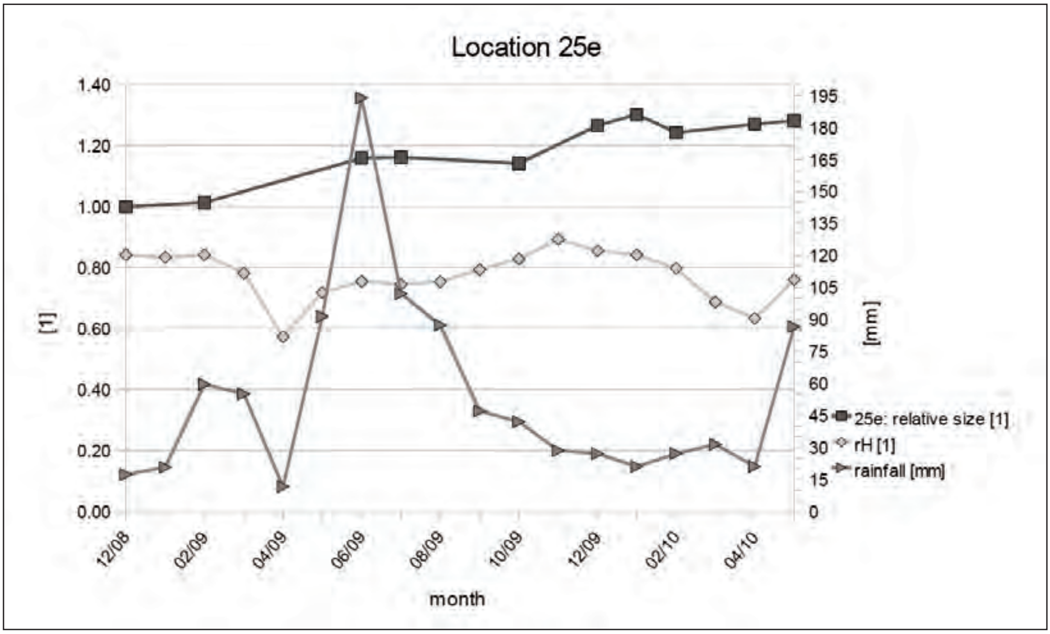

Fig. 57: Relative lichen size of *Phaeophyscia orbicularis* on location 25 e, relative air humidity (rH) and rainfall (average values of Linz).

decrease was detected. Until the end of the investigation period, *Parmelia sulcata* again gained thallus area (Fig. 57).

5.1.22 Location 26

26a

On location 26a, *Xanthoria parietina* showed a quite linear growth behaviour, as it indicated by the trend line equation. Therefore, a monthly growth rate of 5 % can be assumed. During the whole investigation period a total growth of 2,34 cm^2 was observed. This equates to a relative gain of thallus size of 89 %. In the period of one year (December 2008 to December 2009), a growth of 1,58 cm^2 or 60 % was detected (Fig. 58).

26b

Parmelia sulcata started with a period of slow growth and even a decrease. In the following, periods of growth and decline took it in turns. Finally, in the last investigation span from March to May 2010 thallus area again decreased. All things considered, area increased at 0,21 cm^2 during the whole investigation period which equates to 23 % relative growth. During the time span of one year (in this case May 2009 to May 2010), an increase of 0,17 cm^2 or 19 % was observed (Fig. 59).

5.1.23 Location 27

On measurement site 27, *Parmelina tiliacea* (27a) and *Parmelia sulcata* (27b) have been investigated. Both lichens perform very similarly and show with 36 % (27a) and 33 % (27b) nearly the same increase in thallus size during the investigation period. This equates to a total growth of 3,29 cm^2 in case of *Parmelina tiliacea* and 0,97 cm^2 in case of *Parmelia sulcata.* During one year (December 2008 to December 2009) *Parmelina tiliacea* increased 2,99 cm^2 or 33 %. In the same time span, *Parmelia sulcata* showed an increase of 0,6 cm^2 or 20 % (Fig. 60).

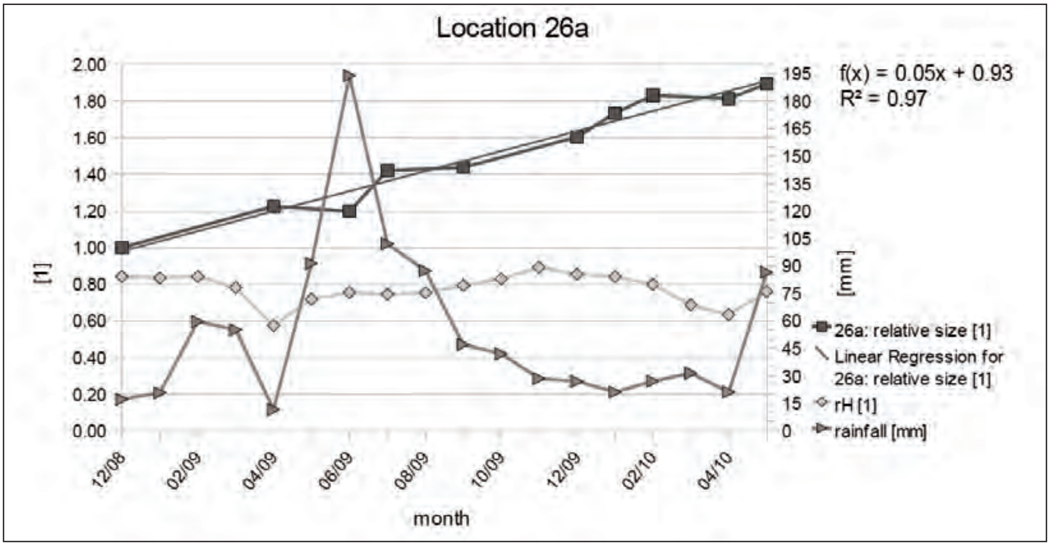

Fig. 58: Relative lichen size of *Xanthoria parietina* on location 26a, relative air humidity (rH) and rainfall (average values of Linz).

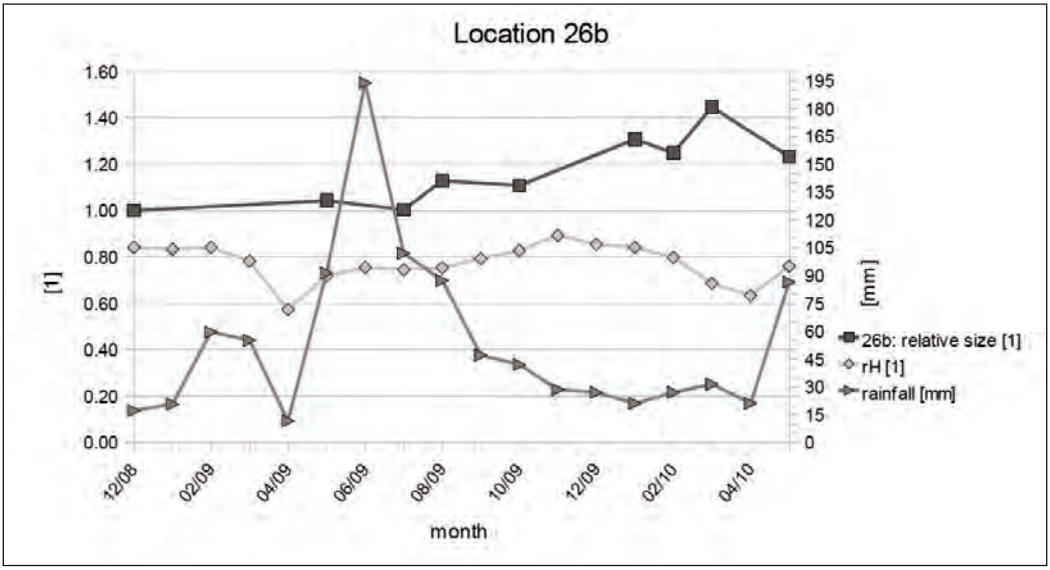

Fig. 59: Relative lichen size of *Parmelia sulcata* on location 26b, relative air humidity (rH) and rainfall (average values of Linz).

5.1.24 Location 29

On measurement site 29 (see Fig. 61), two individuals of *Xanthoria parietina* (29a, d), one example of *Phaeophycia orbicularis* (27b) and on individual of *Parmelia sulcata* (29c) have been investigated. Due to intensive damages *Xanthoria parietina* (29a) and *Phaeophyscia orbicularis* (29b) could not be measured any more after June 2009. In contrast, the second individual of *Xanthoria parietina* developed very well with a total in-

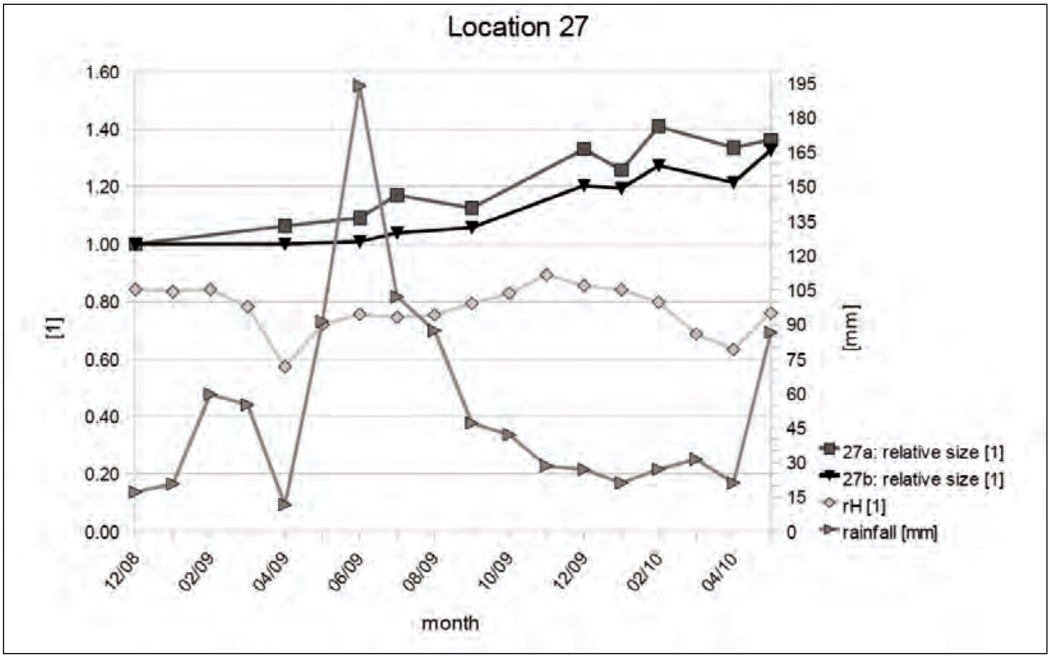

Fig. 60: Relative lichen size on location 27 (27a: *Parmelina tiliacea*, 27b: *Parmelia sulcata*), relative air humidity (rH) and rainfall (average values of Linz).

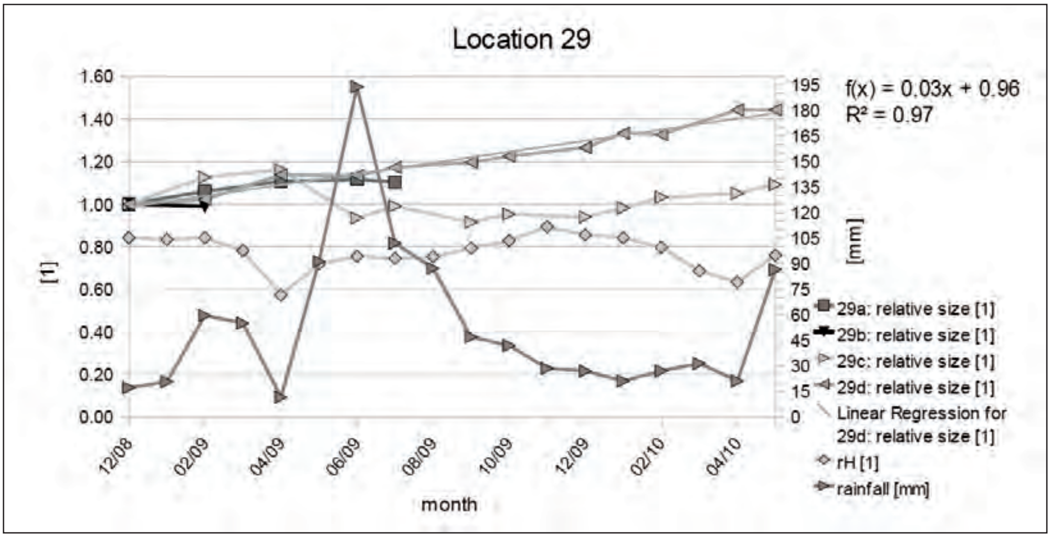

Fig. 61: Relative lichen size on location 29 (29a: *Xanthoria parietina*, 29b: *Parmelia sulcata*, 29c: , 29d: *Xanthoria parietina*), relative air humidity (rH) and rainfall (average values of Linz).

crease of 1,31 cm^2 (44 %). If a linear growth pattern is assumed, a monthly increase of 3 % is indicated by the trend line equation. During one year (February 2009 - February 2010), area increases of 0,9 cm^2 or 30 % were observed. The thallus area of *Parmelia sulcata* (29c) first increased until April 2009, then decreased until June, followed by several changes in growth rate. Thallus size increased again and this resulted in an total gain of 0,23 cm² or 9 %. Finally, from February 2009 to February 2010, a decrease of -0,23 cm² (-9 %) was detected.

5.1.25 Location 30

Phaeophyscia orbicularis was investigated on measurement site 30b. The individual of *Xanthoria parietina* which was observed at 30a, was damaged to strongly, so that measurement had to be stopped by June 2009. The thallus size of *Phaeophyscia orbicularis* further increased by 0,32 cm² in thallus area during the investigation period. This is equal to a relative growth of 23 %. In the time span of one year, a total growth of 0,23 cm² was observed (16 %). Except for one slight decrease from September to October 2009, growth was quite regularly (Fig. 62).

5.1.26 Location 31

Xanthoria parietina (31a) and *Phaeophyscia orbicularis* (31b) have been observed at measurement site 31. The thallus size of *Phaeophyscia orbicularis* increased during the investigation period, although there were some variations in the rate over time. In total, a growth of 0,16 cm² was observed (26 %). During one year (February 2009 to February 2010), the lichen extended due to the same level, +0,16 cm² (26 %). In contrast, *Xanthoria parietina* showed good growth in the beginning, but started to shrink beginning from July 2009 on. Although there were some periods of positive growth, *Xanthoria parietina* did not recover again. A total area gain of only 0,06 cm² was observed during the whole investigaion period, which equates to a relative growth of 8 %. During the time span of one year (February 2009 to February 2010), a decrease of -0,16 cm² or -22 % has been detected (Fig. 63).

5.1.27 Location 32

On location 32, *Xanthoria parietina* (32c) showed the best performance. During the investigation period, it showed an increase in thallus size of 0,78 cm² or 133 %. Within one year (February 2009 to February

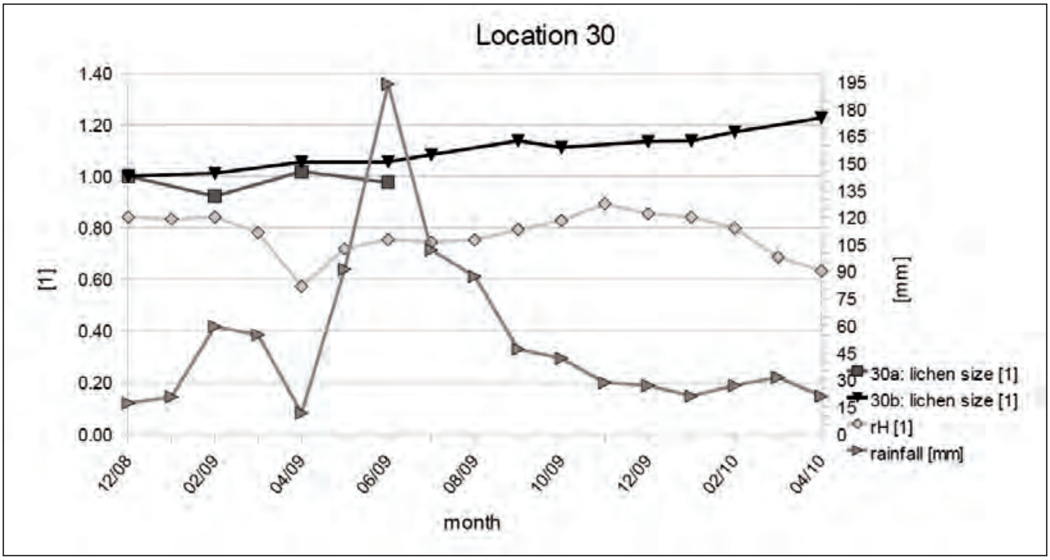

Fig. 62: Relative lichen size of *Phaeophyscia orbicularis* on location 30, relative air humidity (rH) and rainfall (average values of Linz).

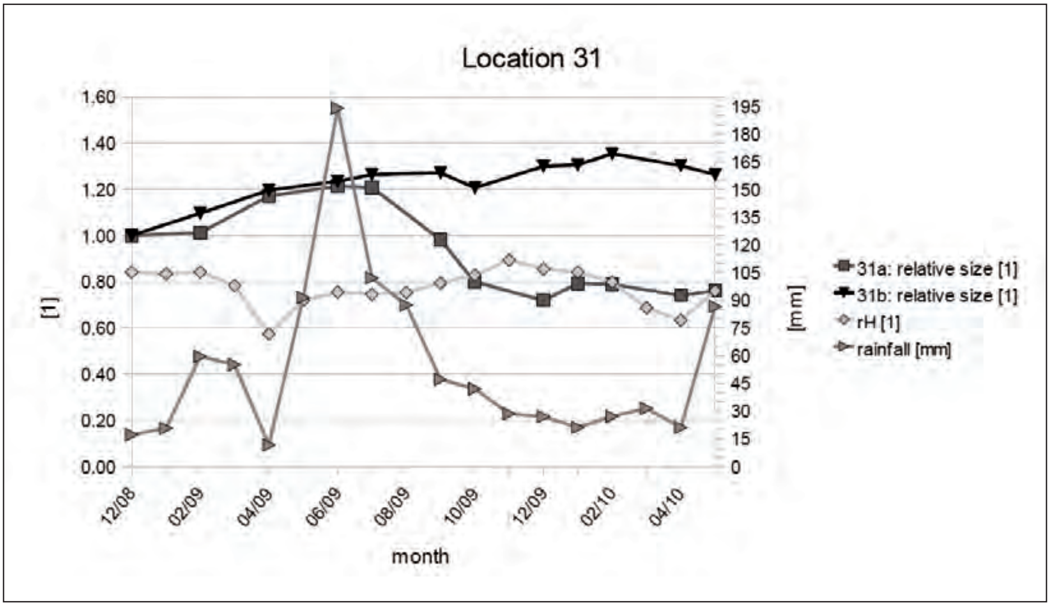

Fig. 63: Relative lichen size on location 31 (31a: *Xanthoria parietina*, 31b: *Phaeophyscia orbicularis*), relative air humidity (rH) and rainfall (average values of Linz).

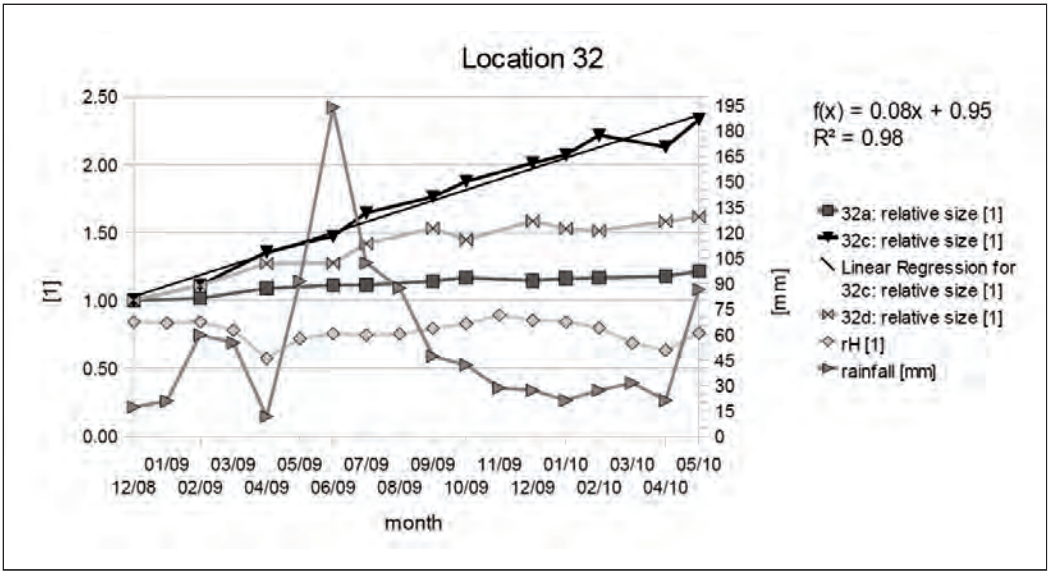

Fig. 64: Relative lichen size on location 32 (32a: *Phaeophyscia orbicularis*, 32b: *Parmelia sulcata*, 32c: *Xanthoria parietina*), relative air humidity (rH) and rainfall (average values of Linz).

2010), an area gain of 0,65 cm^2 or 111 % was observed. According to the trend line equation, a monthly growth rate of 8 % can be assumed. For the second individual of *Xanthoria parietina* (32d), did gain 0,9 cm^2 or 62 % in thallus area was observed and from February 2009 to February 2010, a growth of 0,75 cm^2 or 51 % was detected.

In contrast, *Phaeophyscia orbicularis* only showed a slight increase of 0,11 cm^2 or 21 %. In the period from February 2009 to February 2010, a total growth of 0,08 cm^2 (15 %) has been observed (Fig. 64).

5.1.28 Growth of different lichen species and traffic impact

The measurement locations have been classified into three different categories, in accordance to the traffic impact. These categories have been identified on the basis of the JDTV (daily traffic, annual average) on the road network in Linz (Sturm & Vogelsang 2007). The first category is "without direct traffic impact" (Category 1), the second one was named "with low traffic impact" (Category 2) and finally category "with high traffic impact" (Category 3). In the scatter plot, the results are displayed (see Fig. 65).

Although the annual growth values seem to be quite randomly distributed, the trend lines give some evidence for the performance of the lichen species *Xanthoria parietina*, *Parmelia sulcata* and *Phaeophyscia orbicularis*. While *Xanthoria parietina* seems to be "unimpressed" with some exceptions, the annual growth of *Phaeophyscia orbicularis* increases with higher traffic impact. By contrast, the annual growth of *Parmelia sulcata* is lower with rising traffic density, sometimes thallus surface area even decreases. Especially *Xanthoria parietina* shows a broad variety in its performance. On locations with high traffic impact, it shows extreme values: highest growth rate on some of these laces as well as decrease in thallus size and extreme damage on the other sites strongly affected by traffic.

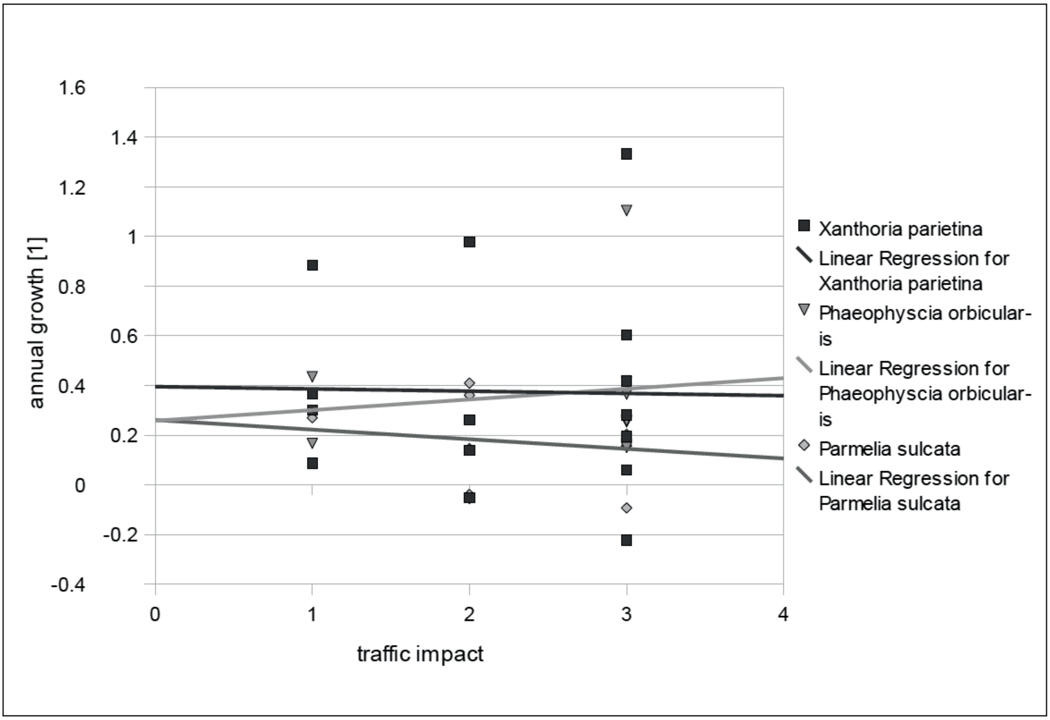

Fig. 65: Scatter plot of the annual growth of different lichens in relation with the traffic impact (1=without direct traffic impact, 2=with low traffic impact, 3=with high traffic impact and trend lines.

6 DISCUSSION

6.1 Study sites without direct traffic impact

6.1.1 Location 05, 07, 08 and 09

These sites are located in Steyregg with a very low direct influence of traffic. Measurement station Steyregg-Au detected relatively low NO and NO_2-levels in comparison to the other stations in Linz. However, the immission of SO_2 and H_2S is higher in Steyregg than on any other station of Linz, which may be because of the higher industrial impact. *Xanthoria parietina* on location 5 gained 25 % in area during the whole period. From April to June 2009, a decrease was observed. April was extraordinary warm and dry, as shown by Amt der Oö Landesregierung 2010d, followed by a warm and wet May. After this event, thallus size increased again very likely, which could have been caused by the higher precipitation. Due to their poikiloyhydric nature, as Gombert et al. (2003) assumed, the uptake of nutrients is greatest in lichens and mosses during wet periods. The second individual of *Xanthoria parietina* (location 7) showed a similar behavior during this period. According to Than & Türk (2008), a strong influence of the industrial areas cannot be ruled out because of the orographical situation. This is also reflected by a higher SO_2 immission load in Steyregg, detected by measurement station Steyregg-Au. NO and NO_2 immission values are lower than on other stations, because of the lower direct traffic-impact. Than & Türk (2008) also pointed out that the impact of air pollution is quite high in Steyregg based on the analysis of lichen diversity and on their abundance. In many parts of Steyregg, trees were free of lichens and covered by algae instead. Franzen-Reuter (2004) has found that the occurrence of filamentary green algae on trees also indicates a high percentage of nitrogen containing compounds in the air. Anyway, *Xanthoria parietina* seems to cope very well with the overall conditions and gained 36 % in thallus area on location 7. On location 8 *Phaeophyscia orbicularis* showed a very strong growth. The growth rate was quite linear and did not show reaction to the variable environmental conditions like precipitation rates. The fact that this nitrophytic species grows very well here, does not necessarily mean that there is a high impact of traffic. Although Windisch 2010 showed that *Phaeophyscia orbicularis* is more frequent near high traffic streets than on remote places, it could also be an effect of little competition. The increasing role of nitrogen compounds in the atmosphere leaded to an extreme shift in the lichen population towards of eutrophic species (VDI 2005). Acidophytic species cannot cope with these conditions. Van Herk et al. (2003) assumed that also long distance nitrogen air pollution has a strong impact on the distribution of acidophytic lichen species. *Parmelia sulcata,* a nitrogen tolerant lichen showed an continuous growth until October 2009. From October to December 2009, a decrease of 15 % occurred. This may be due to inversion weather situations in this period from October to December 2009 with high concentrations of NO_x and particulate matter that have been observed by Amt der Oö Landesregierung 2010d. Although the inversion layer is normally situated at lower altitudes than the measurement site, high concentrations could occur during the dissolution and therefore still affect the lichens. As Than & Türk (2008) found out, *Parmelia sulcata*, like the observed individual, often shows thallus discolouration in highly polluted areas in Linz.

The lichens on this locations showed a similar growth behaviour and increased thallus size beside some events of decrease. The influence of SO_2 is highest in Seyregg which is due to the orographic situation in Linz. Overall, the lichen diversity is still lower in Steyregg.

6.1.2 Location 15

Measurement site 15 is located near a small road and was only accessible from November 2008 to October 2009, because the tree was cut in November 2009. There is no measurement station close to the location. Than & Türk (2008) showed that this area is of high air quality. This may be due to the cleaning winds from the Haselgraben and because the location is situated above the usual inversion layers. Both individuals of *Xanthoria parietina* showed a quite similar growth pattern, although measurement of 15b primary began in February 2009. Individual 15a showed a decrease in thallus size of 15 % in the beginning from November 2008 to February 2009. Rydzak (1961) showed in his diagrams on the annual increase of epiphytic lichens that shrinking can occur. Regarding *Xanthoria parietina*, similar behaviour was observed by Moxham (1981). In the first half of January inversion weather situations occurred and several times and these prevented, combined with infirm winds, an evacuation of air pollutants (Amt der Oö Landesregierung 2010d). Green-algal lichens are depending on nitrogen deposition on the thallus surface to full-fill their nitrogen requirements. This is the reason why they are sensitive to NH_3 in the atmosphere because the depositions directly enter the thallus and cannot be excreted actively. Ammonia is usually deposited near the emitter but it can also be converted into NH_4^+ particles which can be transported over larger areas. NH_3 can stay in the atmosphere between some hours to 4 days (Paoli et al. 2010). Added to the inversion weather situations, precipitation was also low in this period, which causes that the aeorosols stay in the air and cannot be cleared. This situation finds also its reflection in the relatively low values of wet deposition (fig. 122-123). From June to July 2009, both lichen species showed a strong increase. This could be due to the higher precipitation in June and the general high relative air humidity. Lichen growth is restricted to metabolic active periods. Because they are poikiloydric organisms, these periods occur during wet occasions (Palmqvist & Sundberg 2000).

6.1.3 Location 16, 17, 18 and 19

These locations are situated nearby the Pichlinger lake with quite low influence by traffic. There was no measurement station close to the location. Overall, in Linz, the immission of pollutants was highest during the winter and spring months. This may be due to the lower cleaning by rainfall during this months. This is also reflected by the performance of wet and dry deposition. Xanthoria parietina (16) increased its thallus size by 45 %. From June to September 2009 a decrease of -21 % occurred. This could be due to a high pollution load because of wet deposition. June 2009 was very wet and therefore one of the clearest in the century, according to Amt der Oö Landesregierung 2010d. Precipitation washes out aerosols from the atmosphere which results in high wet deposition. This important source of nutrients for lichens can also cause stress when too much at once is deposited. Constant deposition for sure is less stress than one event that washes out a lot of pollutants at once after a long accumulation period. Most frequent emissions in traffic are NO_x and in small amounts SO_2. These transform under influence of water vapour and ozone into ammonium nitrate (NH_4NO_3) or ammonium sulphate ($(NH_4)_2SO_4$). Ammonium nitrate (main content of many fertilizers) is a quite stable salt that leads to osmotic troubles in lichens (Frahm 2008). On location 17, Melanohelia exasperatula (17a), Xanthoria parietina (17b) and Phaeophyscia orbicularis (17c) have been observed. Melanohelia exasperatula was strongly damaged, so that measurement was not possible after June 2009. This lichen species is, according to Wirth (1992), very toxitolerant, but sensitive to nitrogen eutrophication. The observed individual is under strong impact of competition by *Physcia* and *Phaeophyscia* species, which are highly eutrophication tolerant. Nitrogen tolerant to nitrophytic bnefit from the higher concentrations of nitrogen compounds in the atmosphere (VDI 2005). Neutrophytes also benefit from substances like NH_3, but the critical treshold is lower than the concentrations that can be tolerated by of nitrophytic lichens (Jovan 2008). In agreement to that, *Xanthoria parietina* (17b) and *Phaeophyscia orbicularis* (17c) performed much better on this location. Both lichens increased thallus size frequently with a short period of stagnation from December 2009 to January 2010. This could be due to a lower precipitation rate and therefore less availability of liquid water. *Phaeophyscia orbicularis* on location 18 showed only a slight growth in area with no extreme changes in growth rate. *Melanohelia exasperatula* on location 19 gained 28 % in thallus size. Growth stagnated from April to June 2009 which may be due to the dry weather conditions in May and April.

In summary, *Xanthoria parietina* and *Phaeophyscia orbicularis* performed very well in these locations. There were also events of thallus decrease, maybe caused by wet deposition or washing in of accumulated dry deposition. The locations are in general under low impact of traffic, in Steyregg, the SO_2-imissions are higher.

6.2 Study sites with low traffic impact

6.2.1 Location 01 and 02

Both study sites are situated in urban housing areas in the north of Linz. According to the overall situation in Linz, immissions were highest in the winter and spring months, as well as dry deposition. Wet deposition was higher in summer correlating with higher rainfall. On Location 1 (*Parmlia sulcata*), a growth of 55 % was detected. In September 2009, a peak in the growth performance was observed. Although August 2009 was extraordinary wet, no special relation to weather conditions or air pollutants could be assumed. Maybe the event was unique or due to a measurement error, because *Parmelia sulcata* is a foliose lichens with overlapping lobes which makes it difficult to measure growth. Even Armstrong & Smith (1996) suggested that growth of a *Parmelia* species is determined by changes in single lobe growth. On location 2, *Xanthoria parietina* showed a total growth of 45 %. A major part of the inner thallus broke away, whilst the outline of the lichen was not affected. This can be observed frequently in this lichen species. The central, apothecia covered, thallus areas of *Xanthoria parietina* mostly loses their contact to the bark. Because of drought stress, cracks occur and lead to a break off of thallus fragments. These parts can regenerate new lobes if they land on suitable substrates which is a form of vegetative reproduction very typical for lichens (Honegger 1996).

6.2.2 Location 10

Study site 10 is under moderate traffic influence, located in a suburb south-westerly of Linz. Two *Melanelia sp.* individuals and one *Parmelia sulcata* have been observed. From November 2008 to July 2009, a growth of 7 % was detected. Then the thallus size began to decrease. In October 2009, parts of the outer thallus were missing. This may be due to snail grazing, because some slime has been found near the thallus. Snail grazing is a common phenomenon and can decimate lichen populations as has also been shown by Abel & Zimmer GBR (1998). During evolution this grazing stress may have led to a higher investment in lichen compounds for herbivore defence (Gauslaa 2004). The second *Melanelia* species was also damaged after a short period of growth. It was not possible to identify the reason for the impairment. *Parmelia sulcata* on location 10c showed a gain in area of 24 % during the whole investigation period. After a period of growth until September 2009, thallus size decreased until February, followed by another increase. This decrease could have also occurred because of snail grazing. Some grazing marks have been found on the outer thallus. All species on location 10 are under strong competition with *Physcia adscendens*. This may also lead to a lower resistance against damaging. *Physcia* species seem to be more tolerable against nitrogen pollution because of their low cation exchange capacity. As often mentioned, lichen communities respond to atmospheric concentrations of NO_2 and the proportion of nitrophytes within total lichen cover is a useful index (Gadsdon et al. 2010).

6.2.3 Location 12

Location 12 is situated near the housing area of Wagram, a suburb south-westerly of Linz, close to a forest. The investigated individual of *Xanthoria parietina* showed a strong growth during the investigation period and gained 129 % in thallus size. The growth performance was approximately exponential during this period. By dividing the growth curve into two periods, a stronger growth rate can bee detected from July 2009 on. The high precipitation in June 2009 and a quite high relative humidity in the following months may have supported this strong growth behaviour. This location may take a exceptional position, because it is on the edge of a forest. Usually, with increasing impact of eutrophication, in shady or rain sheltered habitats, free living green algae replace Graphidion and Calicion communities. This can be seen in the forests of Steyregg too (Pfenningberg, Than & Türk 2008). In light-flooded and rain-exposed habitats, member species of the Xanthorion parietinae, replace acidophytic communities which are not tolerant to an increase of substratum pH caused by ammonia (Hauck 2010). Location 12 may take an intermediate position on the edge of a forest, indicated by the accompanying species, which are members of the Graphidion community.

6.2.4 Location 20, 21, 22 and 23

The locations are situated in a park south of the city centre that is a water protection area for Linz. On this measurement sites, two individuals of *Xanthoria parietina* (20, 23a), three individuals of *Parmelia sulcata* (22, 23b, 23c) and one individual of *Phaeophyscia orbicularis* (21) have been observed. Both *Xanthoria parietina* showed a net growth, while the gain of area was stronger in location 20 with 47 % than in location 23a with 24 %. In both lichens, growth was quite linear with no special events or an intermittent decrease. Investigation of 23a was quite difficult because of the craggy bark surface. Nevertheless, this individual was affected by strong competition with *Physcia adscendens,* which may have led to a lower growth rate. *Parmelia sulcata* on measurement site 22 demonstrated a quite fluctuating growth performance. Obviously this was due to the fact that the individual is growing in a bark cleft. This makes it difficult to measure the correct size of the thallus. The other two individuals of Parmelia sulcata showed a quite continuous growth. Growth rate of both lichens increased after April 2009. May 2009 was an extraordinary warm and wet month. In areas with less air pollution, the most important factor for lichen growth is the availability of water in the form of precipitation, fog or dew (Polony & Türk 1991). Armstrong (1973) observed that peaks in growth of *Parmelia* species correlate with the highest precipitation rates. *Phaeophyscia orbicularis* (location 21) increased only 1 % in thallus area during the whole investigation period. Windisch (2010) observed that *Phaeophyscia orbicularis* is more frequent near high traffic streets than on remote places. Although Than & Türk (2008) showed that *Phaeophyscia orbicularis* is common in the whole city area, conditions in low-traffic areas may not be optimal for this species. Typical stress factors in urban areas are traffic immissions and overheating caused by buildings. *Phaeophyscia nigricans* and *Phaophyscia orbicularis* are promoted by these factors or tolerate them better than other species (Schnell & Stapper 2009).

On the study sites with low traffic impact, *Xanthoria parietina* showed the best growth performance. *Parmelia sulcata* also showed growth, but it is sometimes difficult to measure because of its irregular growth pattern. Competition with other species and snail grazing are often limiting factors.

6.3 Study sites with high traffic impact

6.3.1 Location 13 and 14

Location 13 and 14 are adjacent to a highly frequented shopping centre in Pasching and the lichen-carrying trees are directly influenced by a main road. NO and NO_2, as well as dry deposition were highest in winter and spring months in Linz. Wet deposition was highest from May to August 2009 and from March to May 2010. Three individuals of *Xanthoria parietina* (13a, 14a, 14b) and one individual of *Phaeophyscia orbicularis* (13b) have been investigated. The three individuals of *Xanthoria parietina* showed approximately linear growth. Both lichens on location 14 increased their growth rate slightly after June 2009, which was high in precipitation. This was not observed with idividual 13a. This growth curve showed a peak in April 2009. The same increase can also be assumed for 14a and 14b, even though to a lesser extent. For *Xanthoria parietina,* Windisch (2010) found out that it is more frequent near high traffic streets, as it is a nutrient tolerate lichen. Growth of 13a was depressed in January and April 2010. In January, there was less precipitation than normal with many inversions, December 2009 was to warm. Variations in growth can also be due to seasonal changes, which has already been shown by Rydzak (1961), Phillips (1963) and Hale (1970). In winter, deciduous trees don´t carry leaves, therefore more light stress can affect the lichens. This can lead to stronger fluctuations in the water saturation of the lichen thallus. Water access is a very important determinant for lichen abundance and growth. Because of high osmotic values, lichens can colonize dry regions due to their ability to take up water from vapour even when air humidity is very low. In dry coastal areas of Malta the nitrophytic lichen *Xanthoria parietina* is very common, but the occurrence of *Ramalina lacera* excludes the impact of nitrogen deposition. Therefore it can be said, that nitrophytes have also xerophytic tendencies (Frahm et al. 2009). Frahm et al. (2009) also described the importance of ammonia as most relevant nitrogen source for lichens. As ammonium nitrate it is deposited on lichens through dry deposition. Because ammonium nitrate is a salt, nitrophytes have higher osmotic values. Therefore they are not necessarily indicators for nitrogen but for drought. The increasing load of particulate matter in form of dry deposition causes still a rise in nitrophytic lichen abundance. On these high traffic locations (13-14), high atmospheric input of ammonia can be assumed. Frahm (2008) recently identified traffic rather catalytic converters as main source for ammonia in urban areas. Ammonia values correlate with the traffic density (Frahm 2006). Added to changeable precipitation, drought stress could be intensified by ammonia input.

On these high traffic locations, high impact of pollutants, especially ammonia, can be assumed. The individuals of *Xanthoria parietina* showed linear growth, except to 13a, which showed some fluctuations.

6.3.2 Location 24 and 25

Location 24 and 25 are situated on traffic islands and directly encircled by main roads with high traffic density. Investigation was carried out on three individuals of *Phaeophyscia orbicularis* (24a, 24c, 25e), two exemplars of *Xanthoria parietina* (24e, 25a), three specimen of *Parmelia sulcata* (25b, 25c, 25d) and one exemple of *Parmelina tiliacea* (24b). The three *Phaeophyscia orbicularis* specimen showed a growth of 35-46 %. Growth seems to be quite linear. Growth of the specimen stagnated in January respectively in February 2010. This may also be due to additional drought stress, caused by low precipitation and impact of pollutants. Dry periods affect lichens not only by the lack of water, but also by higher dry deposition. Dry deposition plays an very important role in case of eutrophication. Usally it is said that NO_x dissolve to nitrous acid (HNO_2) in rain water. This can only happen during rain or high air humidity. In dry periods NO_x bind with ammonia (Frahm et al. 2009). Emitted ammonia reacts chemically very fast under influence of water vapour and ozone into ammonium nitrate. The particle size of ammonium nitrate is 1 µm and forms in general an average of 50 % of the total particulate matter. In opposite to the usually accepted opinion that particulate matter comes from wheel and clutch abrasion or from carbon black, main component is ammonium nitrate (Frahm et al. 2009). Although the specimen of *Phaeophyscia orbicularis* seems to react on changeable precipitation conditions, this species seems to be an indicator for dry deposition and therefore particulate matter. This was shown by Janssen et al. (2007) when they observed an increase in *Ph. orbicularis* abundances whilst wet N-deposition decreases. Dry N-deposition increased instead. The two individuals of *Xanthoria parietina* presented a quite unequal growth behaviour. Specimen 24a gained 76 % in thallus area, while 25a only increased by 19 %. Both show a massive bleaching in the center of the thallus, although the individuals were quite young. This may be a reaction on acidification of the tree bark. Although growth of *Xanthoria parietina* benefits from higher nitrogen deposition, too high impact of traffic emissions may also reduce it´s vitality. Türk & Wirth (1975) already showed the sensitivity of *Xanthoria parietina* to damages under influence of low pH-values. It is often assumed that nitrophyte abundancies increase because of rising bark-pH values as response to particulate matter deposition, but *Xanthoria parietina,* known as nitrophytic species also grows on birch tree which has a acid bark reaction. Additionally, ammonium nitrate shows a acid reaction. Hence it can be said, that nitrophytes are no basiphytes (Frahm et al. 2009). Altogether, these results allow the conclusion that there must be a critical treshold of acidification for *Xanthoria parietina*, which is the reason for thallus damages or total absence of the species on high traffic locations. According to Linz, Than & Türk (2008) showed that on such places, mainly *Phaeophyscia orbicularis* occurs, but not *Xanthoria parietina*. The *Parmelia sulcata* species on this locations showed continuous growth but are also damaged and discoloured. *Parmelina tiliacea* increased very strongly and gained 110 % in thallus size during the investigation period. The individual was under direct competition with *Phaeophyscia orbiculars*. But the strong growth of the typical overlapping lobes of the lichen seem to compensate the impact of *Phaeophyscia orbicularis*. According to Wirth (1995), the species prefers free standing trees with nutrient rich bark, but is missing in highly polluted areas. Due to the fact that the investigated individual was quite young, it is not sure, how it will develop in the following under the influence of this highly trafficked streets. Anyway, this shows that possible habitats can be still recolonised by different lichen species.

As expected, *Phaeophyscia orbicularis* is strongly represented on these locations with a quite linear growth behaviour. *Xanthoria parietina* showed massive bleaching and unequal growth behaviour.

6.3.3 Location 25 and 27

Xanthoria parietina gained 89 % in thallus size during the investigation period and performed a quite linear growth. A decrease was observed from April to June 2009, followed by a strong increase. This may be by reason of a relatively low precipitation in April and a higher availability of nutrients because of the high precipitation in July. *Parmelia sulcata* and *Parmelina tiliacea* performed very similar on location 27 and did also respond to the changing conditions of water availability. Availability of water in the form of fog, precipitation or dew is a very important factor for lichen growth (Polony & Türk 1991). Growth of *Parmelia* species correlates with the high precipitation rates, as Armstrong (1973) indicated. Drought stress can also be amplified by ammonia deposition (Frahm et al. 2009).

The growth of the investigated lichen species was quite linear and reacts to the amounts of rainfall. During the winter and spring months, the impact of immission and dry deposition was highest, whereas wet deposition was higher in summer.

6.3.4 Location 29

Location 29 is situated on a traffic island next to a main road and a tunnel entrance. Measurement station Linz-Römerbergtunnel detected the highest NO and NO_2 imission, as well as particulate matter, compared to other stations. One individual of *Xanthoria parietina* and the specimen of *Phaeophyscia orbicularis* have been intensively damaged. The second *Xanthoria parietina* showed a continuous growth and gained 44 % in thallus size. *Parmelia sulacta* first increased and then strongly decreased in thallus size from April to June 2009. The reason for this event was the braking off of a thallus part. There can be many reasons for such events. Sometimes, because of drought stress, thallus fragments break off and can regenerate, if they land on suitable substrates. On the original lichen thallus, growth of lobes in the areas where thallus fragmentation happened, can be impaired for some time (Polony & Türk 1991). From this date on, it showed again a continuous growth. There were no special events of increase or decrease in thallus size until the end of the investigation period, although a strongly frequented road is close to the investigation site. On the other hand, the location was surrounded by other trees and shrubs. Gadsdon & Power (2009) also showed that NO_2 and NH_3 concentrations rapidly fall with the distance to the road side. Because of the other plants, there is fewer access to direct radiation an therefore lower metabolic activity. The Xanthorion parietinae usually depends on light-flooded and rain-exposed habitats (Hauck 2010). The occurrence of *Xanthoria parietina* on this location therefore may indicate an overall higher availability of nutrients. The sensitivity to high nitrogen concentrations also depends on how effectively deposited pollutants can be taken up. For example, ammonium is very easily and effectively taken up by lichens. High amounts are stored in the extracellular space of the thallus and can also easily be lost to the environment. *Xanthoria parietina* shows a lower extracellular cation exchange capability than less nitrogen tolerant lichens. *E. prunastri* therefore took up significantly more ammonia in cytotoxic amounts, than *X. parietina* (Hauck 2010). For this lichen, a higher uptake ability is necessary, because it normally occurs in nutrient poor habitats.

6.3.5 Location 30 and 31

These two locations are strongly influenced by a main road in the centre of the city. *Phaeophyscia orbicularis* occurs, but the individuals are not very well developed and show bleaching. The same was observed for *Xanthoria parietina* on this location. This species decreased strongly in its size after August 2009. There was high precipitation in July and August which may have led to a higher impact of washed out aerosols. Schumacher et al. (2006) showed that there is no correlation between NO_x-emissions and number of species as well as frequency of nitrophytic lichen species. But NO_x transform under influence of water vapour and ozone into ammonium nitrate (NH_4NHO_3) or ammonium sulphate ($(NH_4)_2SO_4$), which can affect lichens by deposition (Frahm 2008). *Phaeophyscia orbicularis* showed a continuous growth and did not react on stronger wet deposition.

6.3.6 Location 32

This location is situated directly next to an urban highway north of the river Danube. In comparison to other stations, measurement station 24-er-Turm showed higher NO_2 values and also high values of particulate matter. This may be due to the close highway. Additionally, the SO_2 levels are quite high. All lichen species seem to be quite vital and show a continuous growth performance. The strongest growth was observed in one *Xanthoria parietina* specimen, which gained 133 % in thallus area. The second individual of *Xanthoria parietina* only increased at 62 %. *Phaeohyscia orbicularis* showed an intermediate behaviour. There seems to be a slight increase, which may have been caused by the strong precipitation in June 2009. From February to April 2010, a size decrease was observed in individual 32c (*Xanthoria parietina*). In this period, precipitation was extraordinary low and therefore there were more periods of inactivity. Also Polony & Türk (1991) observed, that lichens can show a decrease in thallus area. This effect was not observed with the *Phaeophyscia orbicularis* individual on the same location.

6.4 Growth of different lichen species and traffic impact

The comparison of the different annual growth rates of *Xanthoria parietina*, *Phaeophyscia orbicularis* and *Parmelia sulcata* with the impact of traffic gives some evidence for their performance under pollution stress. The annual growth of *Phaeophyscia orbicularis* shows the trend to increase with higher traffic impact. The reaction of *Xanthoria parietina* were not that uniform and the growth rate of *Parmelia sulcata* decreases with rising traffic impact. Lichens as *Phaeophyscia orbicularis* and *Xanthoria parietina* are more common near highly trafficked streets than on remote places as has been indicated by Windisch (2010). Additionally, Franzen-Reuter (2004) showed that the occurrence of *Phaeophyscia orbicularis* increases with increasing nitrogen deposition. This fits to the recent observation of a higher growth rate under higher traffic influence. Usually, NO_x are seen as the main origin of atmospheric nitrogen load. Although NO_x in general decrease slightly, nitrophile plant species still increase. Many lichen species which were found on trees in urban areas have been known formerly nearby farms. There they respond to higher ammonia concentrations which comes from animal husbandry. Measurements on motorcars with catalytic converters showed that they emit ammonia and therefore affect lichens in urban habitats (Frahm 2008). These studies support the recent observations of decreasing growth rates in *Parmelia sulcata* and rising growth rates in *Phaeophyscia orbicularis.*

6.5 Conclusion

The major result of this work is that the annual growth of *Phaeophyscia orbicularis* increases with higher traffic impact whilst *Xanthoria parietina* shows a higher variation in its reaction. The growth rate of *Parmelia* *sulcata* decreases with higher traffic density. According to the growth of the single lichen species on the different investigation sites, a strong dependence on the availability of water through precipitation is assumed. The investigated lichens show different responses to airborne nitrogen compounds according to the kind of species. The beneficial impact on the growth rate of the lichens, attributable to need of nutrient uptake during wet occasions and the negative effects of airborne nitrogen compounds which are also incorporated during wet periods, is depending on the type of lichen.

7 ZUSAMMENFASSUNG

Die vorliegende Studie über den Einfluss von Luftverunreinigungen auf Flechten untersucht die Beziehung zwischen steigender Emissionsbelastung und Zunahme der neutrophytischen und eutrophen Flechtenarten. Der Einfluss von NO_x und deren Derivaten wie Ammoniak auf das Wachstum ausgewählter Flechtenarten wurde dargestellt. Es werden Unterschiede zwischen verkehrsnahen und verkehrsfernen Habitaten herausgearbeitet, die in vielen klassischen Monitoringkonzepten nicht inkludiert sind. Außerdem wurde eine kosteneffektive und zeiteffiziente Methode zum Messen des Flechtenwachstums getestet. Diese Fotografie-basierte Methode erlaubt die Dokumentation des Flechtenwachstums über einen langen Zeitraum (cf. McCarthy & Zaniewski 2001). Untersucht wurden die Flechtenarten *Xanthoria parietina*, *Phaeophyscia orbicularis* und *Parmelia sulcata*. Die unterschiedlichen Wachstumsraten der Flechten wurden mit dem Verkehrseinfluss der Standorte verglichen und geben Hinweise auf deren Verhalten unter dem Einfluss von Luftverunreinigungen. Die jährlichen Wachstumsraten von *Phaeophyscia orbicularis* steigen mit höherem Verkehrseinfluss, während *Xanthoria parietina* stärkere Variationen zeigt. *Parmelia sulcata* zeigt verringertes Wachstum bei höherem Verkehrseinfluss. Bezogen auf das Wachstum der einzelnen Flechtenarten an den unterschiedlichen Standorten scheint eine starke Abhängigkeit von der Verfügbarkeit von Niederschlag zu bestehen. Die untersuchten Flechtenarten reagieren unterschiedlich auf die verschiedenen Schadeinflüsse. Während Niederschlagsereignisse wichtig für die Nährstoffaufnahme sind, werden auch verstärkt deponierte Schadstoffe aus nasser und trockener Deposition aufgenommen.

8 REFERENCES

Abel & Zimmer GBR (1998): Flechtenbiomonitoring an Bodendauerbeobachtungsflächen in Schleswig-Holstein. *http://www.schleswig-holstein.de/cae/servlet/contentblob/611934/publicationFile/BerichtFlechtenkunde_pdf.pdf.* Downloaddatum 12. 11. 2010

Ahmadijan V. (1993): The lichen symbiosis. John Wiley & Sons, New York.

Amt der Oö. Landesregierung (2005): Langfristige Entwicklung der Luftschadstoffe in Oberösterreich. *http://www.land-oberoesterreich.gv.at/cps/rde/xchg/SID3DCFCFC3FAE455AC/ooe/hs.xsl/17682_DEU_HTML.htm* , Abrufdatum: 12. 12. 2006

Amt der Oö. Landesregierung (2006): DORIS interMap. Karte: Genisys NaLa2000. *http://www.doris.gv.at*, Abrufdatum: 12. 12. 2006 x

Amt der Oö. Landesregierung (2006): Grenzwerte des Immissionsschutzgesetzes Luft. BGBl. I. Nr. 115 (1997) in der Fassung BGBl. I Nr. 34 (2006) vom 16. März 2006

Amt der Oö. Landesregierung (2009): Jahresbericht 2008 der Luftgüteüberwachung in Oberösterreich. Inspektionsbericht. Umwelt Prüf- und Überwachungsstelle, Linz.

Amt der Oö. Landesregierung (2010): Emissionen in Österreich. *http://www.land-oberoesterreich.gv.at/cps/rde/*

xchg/SID-29E32B52-2CF7122F/ooe/hs.xsl/17354_DEU_HTML.htm, Abrufdatum: 19. 11. 2010

Amt der Oö. Landesregierung (2010b): Emissionstrends (2002-2007). *http://www.land-oberoesterreich.gv.at/cps/rde/xchg/SID-29E32B52-2CF7122F/ooe/hs.xsl/41717_DEU_HTML.htm*, Abrufdatum: 19. 11. 2010

Amt der Oö. Landesregierung (2010c): Aktualisierung der Statuserhebung für NO_2 in Linz. Ergänzende Daten für die Jahre 2005 bis 2009.

Amt der Oö. Landesregierung (2010d): Jahresbericht 2009 der Luftgüteüberwachung in Oberösterreich. Inspektionsbericht. Umwelt Prüf- und Überwachungsstelle, Linz.

Amt der Oö. Landesregierung (2010e): Inspektionsberichte des oö Luftmessnetzes. Jänner - Mai 2010. Umwelt Prüf- und Überwachungsstelle, Linz.

Armstrong R. A. (1973): Seasonal growth and growth-rate colony size relationships of six species of saxicolous lichens. New Phytologist 72: 1023-1030.

Armstrong R. A. (1993): Seasonal growth of foliose lichens in successive years in South Gwynedd, Wales. Environmental and Experimental Botany 33: 225-232.

Armstrong R. A. (1993b): Factos determining lobe growth in foliose lichen thalli. New. Phtol. 124: 675-679.

Armstrong R. A., Smith S. N. (1996): Factors determining the growth curve of the foliose lichen *Parmelia conspersa*. New. Phytol. 134: 517-522.

Arnold F. (1891, 1892, 1897, 1899, 1900a, 1900b): Zur Lichenenflora in München. Berichte der Bayrischen Botanischen Gesellschaft 1: 1-147, 2: 1-76, 5: 1-45, 6: 1-82, 7, 8.

Beschel R. (1958): Flechtenvereine der Städte – Stadtflechten und ihr Wachstum. Ber. Naturwiss.-med. Ver. Innsbruck 52: 1-158.

Bortenschlager S., Schmidt H. (1963): Untersuchung über die epixyle Flechtenvegetation im Großraum Linz. Naturk. Jahrb. Stadt Linz 1963: 19-35 + Karten.

Conti M. E., Cecchetti G. (2001): Biological monitoring: lichens as bioindicators of air pollution - a review. Environmental Pollution 114: 471-492.

Dahlman L. (2003): Resource acquisition and allocation in Lichens. PhD-thesis. Department of Ecology and Environmental service, Umea University.

Dahlman L., Persson J., Palmqvist K., Näsholm T. (2004): Organic and inorganic nitrogen uptake in lichens. Planta 219: 459-467.

De Bruyn U., Linders H.-W., Mohr K. (2009): Epiphytische Flechten im Wandel von Immissionen und Klima. Ergebnisse einer Vergleichskartierung 1989/2007 in Nordwestdeutschland. Umweltwiss. Schadst. Forsch. 21: 63-75.

Egan R. S. (2010): Lichens and Air pollution. Power Point Lecture: *http://www.unomaha.edu/lichens/Bio%204350%20PDF/Lichens%20and%20Air%20Pollution.pdf*. Downloaddatum: 16. 12. 2010

European Commission (1997): Position paper on Air Quality: nitrogen dioxide. Working Group on Nitrogen Dioxide.

Frahm J.-P. (2006): Der Einfluss von Ammoniak auf Stickstoff liebende Flechten in verkehrsbelasteten Gebieten. Immissionsschutz 4/2006.

Frahm J.-P. (2008): Überdüngung und Versalzung durch Kalaysatoren? Nitrophile Moose und Flechten nehmen zu. Biologie unserer Zeit 2/2008 (38). 94-101.

Frahm J.-P., Solga A. (1999): Der Einfluss von Stickstoffemissionen auf Moose und Flechten. Bryologische Rundbriefe 28. 1-10.

Frahm J.-P., Janssen A.-M., Schumacher J., Thönnes D., Hensel S., Heidelbach B., Erler D. (2009): Das Nitrophytenproblem bei eipiphytischen Flechten - eine Synthese. Archive For Lichenology Vol 05.

Franzen I., Stapper N.J., Frahm J.-P. (2002): Ermittlung der lufthygienischen Situation Nordrhein-Westfalens mit epiphytischen Flechten und Moosen als Bioindikatoren. *http://www.bryologie.uni-bonn.de/deutsch/frame.htm* . Abrufdatum 12. 12. 2006

Franzen-Reuter I., Stapper N. (2003): Epiphytenkartierung: Nachweis eutrophierender Luftverunreinigungen in NRW. Landesweite Kartierung epiphytischer Flechten und Moose. LÖBF-Mitteilungen 1/03: 76-78.

Franzen-Reuter I. (2004): Untersuchungen zu den Auswirkungen atmosphärischer Stickstoffeinträge auf epiphytische Flechten und Moose im Hinblick auf die Bioindikation.

Dissertation an der Rheinischen Friedrich-Wilhelms-Universität Bonn.

Frati L., Brunialti G., Loppi S. (2008): Effects of reduced nitrogen compunds on piphytic lichen communities in Mediterranean Italy. Science of the total Environment 408. 630-637.

Gadsdon S. R., Power S. A. (2009): Quantifying local traffic contributions to NO_2 and NH_3 concentrations in natural habitats. Environmental Pollution 157. 2845-2852.

Gadsdon S. R., Dagley J. R., Wolseley P. A., Power S. A. (2010): Relationships between lichen community composition and concentrations of NO_2 and NH_3. Environmental Pollution 158. 2553-2560.

Gaio-Oliveira G., Dahlmann L., Pamqvist K. Martins-Loução M. A., Máguas C. (2005): Nitrogen uptake in relation to excess supply and its effects on the lichens *Evernia prunastri* (L.) Ach and *Xanthoria parietina* (L.) Th. Fr.. Planta 220: 794-803.

Gauslaa, Y. (2005): Lichen palatability depends on investments in herbivore defence. Oecologie 143: 94-105.

GIMP Developement Team (2010): GNU Image Manipulation Program. *www.gimp.org*

Gombert S. (1999): Utilisation de la bioindication lichénique dans l'estimation de la qualité de l'air de l'agglomération grenobloise: étude à différents niveaux d'organisation biologique. PhD Thesis, University of Josef Fourier, France

Gombert S., Asta J. (2000): Effet des nitrates et du NO_2 sur lichens et tabac: activité de la nitrat-réductase, teneur en azote total et en nitrates. Abstract and Poster, PRIMEQUAL-PREDIT 1996-2000, Toulouse.

Gombert S., Asta J., Seaward M. R. D. (2003): Correlation between the nitrogen concentration of two epiphytic lichens and the traffic density in an urban area. Environmental Pollution 123. 281-290.

Hale M. E. (1970): Single-lobe growth-rate patterns in the lichen *Parmelia caperata*, Bryologist 73. 72-81.

Hauck M. (2009): Flechten und Schadstoffe. Rundgespräche der Kommission für Ökologie, Bd. 36 "ökologische Rolle der Flechten". 83-92.

Hauck M. (2010): Ammonium and nitrate tolerance in lichens. Environmental Pollution 158. 1127-1133.

Heber I., Heber W., Türk R. (1992): Ergebnisse der Flechtenexpositionen (Oktober 1990 bis Oktober 1991) für die Feststellung der Luftqualität in Linz. *http://www.linz.gv.at/Umwelt/umwelt_27831.asp*, Abrufdatum 12. 12. 2006

Herk C.M. van (1999): Mapping of ammonia pollution with epiphytic lichens in The Netherlands. Lichenologist 31, 9-20.

Herk C. M. van, Mathijssen-Spiekman E. A. M., Zwart D. de (2003): Long-distance nitrogen air pollution effects on lichens in Europe. Lichenologist 35(4). 347-359.

Hoislbauer G. (1979): Rindenflechten im Oberösterreichischen Zentralraum und ihre Abhängigkeit von Umwelteinflüssen. Stapfia 5.

Honegger R. (1996): Experimental studies of growth and regerative capacity in the foliose lichen Xanthoria parietina. New Phytol. 133: 537-581.

Janssen A.-M., Frahm J.-P., Gehrmann J. (2007): Auswirkungen unterschiedlicher Stickstoffdepositionsformen auf epiphytische Flechten. Immissionsschutz 3/2007: 110-115.

Jovan S. (2008): Lichen Bioindication of Biodiversity, Air Quality and Climate: Baseline Results From Monitoring in Washington, Oregon, and California. United States Department of Agriculture.

Kienesberger A., Pfleger H.S., Than B., Türk R. (2007): Epiphytische Flechten an Probeflächen für immissionsökologische Untersuchungen nach der VDI-Methode 2005 und Untersuchungen für die Artenzusammensetzung in industriefernen Flächen - ein Hinweis für den zunehmenden Einfluss von Stickstoffverbindungen. Kommission zu Reinhaltung der Luft im VDI und DIN-Normenausschuss KRdL, Schriftenreihe Band 37.

Kirschbaum U., Windisch U. (1995): Beurteilung der lufthygienischen Situation Hessens mittels epiphytischer Flechten. Schriftreihe der Hessischen Landesanstalt für Umwelt 171.

Kirschbaum U., Wirth V. (1997): Flechten erkennen – Luftgüte bestimmen. Stuttgart, Ulmer.

Kirschbaum U., Windisch U., Hanewald K. (2010): Immmissionsbezogene Flechtenkartierungen in Hessen von 1992 bis 2007. Gefahrstoffe - Reinhaltung der Luft 2010(4): 135-140.

KLUMPP A., KLUMPP G., ANSEL W. (2004): Urban air quality in Europe. Results of three years of standardised biomonitoring studies. In: KLUMPP A., ANSEL W. KLUMPP G. (Hrsg.): Urban air Pollution, Bioindication and Environmental Awareness. Göttingen, Cuvillier: 25-50.

KRICKE R. (2002): Untersuchungen zur epiphytischen Flechtenvegetation in urbanen Gebieten, dargestellt an der Rückkehr der Flechten in das Ruhrgebiet und ausgewählter Nachbargebiete. Inaugural-Dissertation, Universität Essen.

KRICKE R. (2006): Flechten und Bioindikation. *http://www.flechten-im-ruhrgebiet.de*, Downloaddatum: 05. 12. 2006

KOSTKA-RICK R., LEFFLER U. S., MARKERT B., HERPIN U., LUSCHE M., LEHRKE J. (2001): Biomonitoring zur wirkungsbezogenen Ermittlung der Schadstoffbelastung in terrestrischen Ökosystemen. Konzeption, Durchführung und Beurteilungsmaßstäbe im Rahmen von Genehmigungsverfahren. UWSF - Z. Umweltchem Ökotox 12(1): 5-12.

MCCARTHY D. P., ZANIEWSKI K. (2001): Digital Analysis of Lichen Cover: A Technique for Use in Lichenometry ad Lichenology. Arctic, Antarctic and Alpine Research, Vol. 33, No.1: 107-113.

MARHOLD H. (2003): Feinstaubproblematik in Linz. Grüne Reihe Bericht Nr. 1/2003.

MASUCH G. (1993): Biologie der Flechten. Uni-Taschenbücher. Heidelberg, Quelle und Meyer.

MOHR K. (2007): Biomonitoring von Stickstoffimmissionen. Möglichkeiten und Grenzen von Bioindikationsverfahren. UWSF - Z Umweltchem Ökotox 19(4): 255-264.

MOXHAM T. H. (1981): Growth rates of *Xanthoria parietina* and their relationship to substrat texture. Cryptogamie, Bryol. Lichenol. 2: 171-180.

MURSCH-RADLGRUBER E. (1997): Klimauntersuchung Linz – Basisstudie, Belüftungsrelevante Grundlagen. Universität für Bodenkultur Wien, Institut für Meteorologie und Physik.

MURSCH-RADLGRUBER E. (2002): Wärmeinsel Linz und belüftungsrelevante Strömungssysteme. Linz, Grüne Reihe, Bericht Nr. 7/2002.

NASH III T. H. (2008): Nitrogen, its metabolism and potential contribution to ecosystems. In: NASH III T. H. (Ed.): Lichen Biology. Second Edition, Cambridge, Cambridge University Press.

NIMIS P. L. et al. (2002): Monitoring with lichens - monitoring lichens. Nato Science Series IV. Earth and Environmental Sciences. Vol.7: 1-4.

NIMIS P. L., PURVIS O. W. (2002): Monitoring lichens as indicators for pollution. Monitoring with lichens - monitoring lichens. Nato Science Series IV. Earth and Environmental Sciences. Vol.7: 7-10.

NOBEL W., KOSTKA-RICK R., BARTHOLMESS H. (2008a): Immissions-Wirkungsmessungen Kfz-bedingter Metallimmissionen mit Bioindikatoren an einer Autobahn. Gefahrenstoffe - Reinhaltung der Luft - Biomonitoring. 68, Nr. 6.

NOBEL W., KOSTKA-RICK R., BARTHOLMESS H. (2008b): Erfassung Kfz-bedingter Metallimmissionen mit Bioindikatoren an einer Autobahn. Gefahrstoffe - Reinhaltung der Luft - Biomonitoring. 68, Nr. 6.

NOWAK R. (1973): Vegetationsanalytische und experimentell ökologische Untersuchungen über den Einfluss der Luftverunreinigungen auf rindenbewohnende Flechten. Dissertation an der Eberhard-Karls-Universität Tübingen, Deutschland.

NYLANDER W. (1866): Les lichens du Jardin du Luxembourg. Bulletin de la Societe Botanique de France, Lettres Botaniques 13: 364-372.

PALMQVIST K., SUNDBERG B. (2000): Light use efficiency of dry matter gain in five macrolichens: relative impact of microclimate conditions and species-specific traits. Plant, Cell and Environment 23: 1-14.

PAOLI L., PIRINTSOS S. A., KOTZABASIS K., PISANI T., NAVAKOUDIS E., LOPPI S. (2010): Effects of ammonia from livestock farming on lichen photosynthesis. Environmental pollution 158. 2258-2265.

PEARSON J., STEWART G. (1993): The deposition effects of atmospheric ammonia and it´s effects on plants. New Phytologist 125: 283-305.

PHILLIPS H. C. (1963): Growth rate of *Parmelia isidiosa*. Journal Tennesee Acadamy Sci. 38: 95-96.

POLONY S., TÜRK R. (1991): Wachstum und Lobendifferenzierung der Blattflechte *Parmelia sulcata*. Phyton Vol. 31.

RYDZAK J. (1961): Investigations on the growth rates of lichens. Annals Universitas Mariae Curie-Skldowska Section C, 16: 1-15.

Sancho L. G., Green A. T. G., Pintado A. (2007): Slowest to fastest: Extreme range in lichen growth rates supports their use as an indicator of climate change in Antarctica. Flora - Morphology, Distribution, Functional Ecology of Plants Volume 202, Issue 8: 66-673.

Scheidegger C. (2009): Flechten: Bioindikatoren für Veränderungen in der Umwelt. rundgespräche der Kommission für Ökologie, Bd. 36 "Ökologische Rolle der Flechten": 143-159.

Schnell S., Stapper N.J. (2009): Eine einfache Methode zur Bioindikation der Umweltbelastung in einer Großstadt mit epiphytischen Flechten. Archive for Lichenology 3

Schumacher J., Janssen A.-M., Frahm J. P. (2006): Spiegelt der VDI-Luftgüteindex die schadstoffbelastung durch NO_2 und SO_2 wider? Herzogia 19: 205-213.

Sernander J. R. (1926): Stockholms Naturalist. Almquist and Wiksells, Uppsala.

Starke P. (1983): Stadtklima, Immissionsverhältnisse und Flechtenverbreitung in Linz. Naturk. Jahrb. Stadt Linz 29: 157-284 + Karten.

Stapper N. J. et al. (2000): Moose und Flechten kehren ins Ruhrgebiet zurück. LÖBF Mitteilungen 2/2000: 12-21.

Stapper N. J., Kricke R. (2004): Epiphytische Moose und Flechten als Bioindikatoren von städtischer Überwärmung, Standorteutrophierung und verkehrsbedingten Immissionen. Limprichtia 24: 187-208.

Sturm P., Vogelsang S. (2007): Untersuchung zur NO_2-Belastung im Stadtgebiet von Linz. Institut für Verbrennungskraftmaschinen und Thermodynamik. TU Graz.

Than B., Türk R. (2008): Immissionsökologische Untersuchung der epiphytischen Flechtenvegetation der Stadt Linz. Beträge zur Naturkunde Oberösterreichs 18/2008: 381-409.

Türk R., Hoislbauer G. (1978): Der Flechtenbewuchs von Birn- und Apfelbäumen als Indikator für die Luftverunreinigung im Großraum Linz. Linzer biologische Beiträge 9/2: 213-224.

Türk R., Wirth V. (1975): The pH Dependence of SO_2 Damage to Lichens. Oecologia 19: 285-291.

Türk R., Wittmann H. (1984): Atlas der aktuellen Verbreitung von Flechten in Oberösterreich. Stapfia 11: 1-98.

Türk R., Wittman H. (1988): Flechtenkartierung in Österreich. Ein Beitrag zur Dokumentation des Naturraumpotentials. Natur und Land 576: 98-113.

Türk R., Wittmann H., Roth S., Wögerer I. (1989): Flechtenuntersuchung 1988. Vergleich mit der Untersuchung im Jahre 1978. Grüne Reihe Bericht Nr. 8/89.

Türk R. (1991): Die Organisationsform der Flechten als Grundlage der Bioindikation von Luftfremdstoffen mit Flechten. VDI berichte Nr. 901: 73-80.

Türk R., Poelt J. (1993): Bibliographie der Flechten und flechtenbewohnenden Pilze in Österreich. Verlag der österreichischen Akademie der Wissenschaften, Wien.

Türk R., Wittmann H., Roth S., Wögerer I. (1994): Die Luftqualität im Stadtgebiet von Linz - Untersuchungen über den epiphytischen Flechtenbewuchs im Bezug zur Schadstoffbelastung. Nat.kdl. Jahrb. Stadt Linz 37-39: 457-490.

Türk R., Pfefferkorn V. (1996): Flechten als Zeiger des Hemerobiegrades in terrestrischen Ökosystemen, Sauteria 8: 181-192.

Umweltbundesamt (2004): Medienübergreifende Umweltkontrolle in ausgewählten Gebieten. Monographien M-168.

Vorbeck A., Windisch U. (2001): Flechtenkartierung München. Eignung von Flechten als Bioindikatioren für verkehrsbedingte Immissionen. Bayrisches Landesamt für Umweltschutz.

Windisch U. (2010): Nachweis der Wirkung eutrophierender Immisionen auf Flechten in der Praxis der Bioindikation. Ergebnisse aus Untersuchungen in Hessen und Bayern. *www.fraxinus-online.de*, Downloaddatum: 4. 11. 2010.

Wirth V. (1992): Zeigerwerte von Flechten. In: H. Ellenberg (1992): Zeigerwerte der Pflanzen Mitteleuropas. 2. Auflage. Göttingen, Gölze.

Wirth V. (1995): Flechtenflora: Bestimmung und ökologische Kennzeichnung der Flechten Südwestdeutschlands und angrenzender Gebiete. 2. Aufl.. Stuttgart, Ulmer.

Wirth V. (2002): Indikator Flechte. Naturschutz aus der Flechtenperspektive. Stuttgarter Beiträge zur Naturkunde 50.