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# Immission related lichen mapping in the city zone of Salzburg

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**Abstract:** From April to June 2009 a study in the city zone of Salzburg was conducted to determine the air quality by means of lichen mapping. The method used was the VDI-Guideline 3957 Part 13 according to Verein Deutscher Ingenieure, 2005. The results show that moderate air quality prevails in Salzburg. A comparison with technical measurements of air pollutants reveals an overall pattern, namely that local sites with high air pollutant values obtained by technical measurement also tend to have a rather low air quality obtained by lichen mapping. A comparison with Roth 1988 and Schulmeister 1996 revealed a trend of declining air quality since then. A recalculation of the air quality indices after leaving out the two most abundant lichens shows a severe decline in air quality. Above all, this study is designed to serve as a basis for subsequent studies.

**Zusammenfassung:** Von April bis Juni 2009 wurde in der Stadt Salzburg eine Flechtenkartierung nach der VDI Richtlinie 3957 Teil 13, Verein Deutscher Ingenieure, 2005 durchgeführt. Ziel dieser Kartierung war, die momentane Luftgütesituation in der Stadt und eventuelle Trends festzustellen. Die Ergebnisse zeigten, dass mittlere Luftgüte zum Großteil in der Stadt Salzburg vorherrscht. Ein Vergleich mit technischen Messungen, durchgeführt von der Salzburger Landesregierung, zeigte dahingehend einen Trend, dass jene Orte an denen hohe Werte der gemessenen Parameter festgestellt wurden, auch dazu tendierten bei der Flechtenkartierung eine niedrige Luftgüte aufzuweisen. Ein Vergleich mit Roth 1988 und Schulmeister 1996 zeigte eine sich verschlechternde Luftgütesituation seit damals in der Stadt Salzburg. Aufgrund des Aufbaus der verwendeten Methode wurde eine Neuberechnung der Luftgüte nach Weglassen der zwei häufigsten Arten durchgeführt. Es offenbarte sich eine dramatische Verschlechterung der Luftgüte in Salzburg.

Es ist anzumerken, dass diese Studie so konzipiert wurde, dass sie als Basis für Nachfolgeuntersuchungen herangezogen werden kann.

**Key words:** bioindication, Salzburg/Austria, lichen mapping

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## 1. Introduction

Lichen sensitivity to air pollution has long been recognized and already since the 1800s lichens disappearing from urban areas have been documented (Nash III 2008). Lichens are very well suited for bioindication studies because of their graded sensitivity to immissions (Kreeb 1990). This pattern is related to the biology of lichens (Nash III 2008). The subtle equilibrium between mycobiont and photobiont allows lichens to live in environments with extreme climatic conditions. On the other hand, lichens are very sensitive to anthropogenically caused alterations to the environment (Kricke 2009). The advantage of the use of lichens as bioindicators is that not only one air pollutant but the whole range is accumulated in lichens. Therefore the effect of the pollutants on living organisms can be monitored, whereas physical technical measurements only provide values and the effect on organisms cannot be evaluated.

Roth 1988 and Schulmeister 1996 carried out passive monitoring studies in the city zone of Salzburg. Schulmeister (1996) also used the VDI guideline, although an older edition than the one used in this master thesis which is VDI 3957 Part 13 2005.

In the last 20 years the air quality has significantly improved in Salzburg. Reductions in the release of various air pollutants such as sulphur dioxide (predominantly responsible for acid

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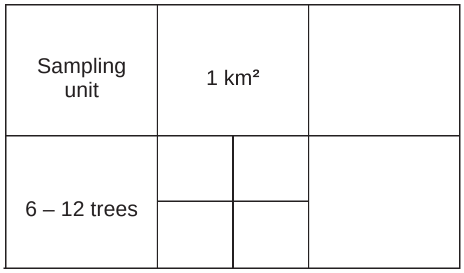


**Fig. 1**: Normal sampling grid for urban areas (VEREIN DEUTSCHER INGENIEURE 2005).

**Fig. 2**: Recording of lichens on the tree trunk.

rain), carbon monoxide, hydrocarbons and benzene lead to ameliorated air quality conditions, as did a reduction of lead by installing flue gas treatments, catalytic converters and lead free and benzene poor fuel (INTERNET 3).

The aim of this study is to assess the current air pollution situation in the city zone of Salzburg, 13 years after the last bioindication study. Besides, this investigation serves as a basis for subsequent passive monitoring studies. Furthermore it assesses if there is a connection between the air quality results obtained using lichens and those gained by physical, technical pollutant measurements of the government of Salzburg. Additionally, a comparison with former studies, ROTH 1988 and SCHULMEISTER 1996, on bioindication with lichens in the city zone of Salzburg will show a trend in change of air quality in either direction.

## 2. Method

The method used for this investigation was VDI (Verein Deutscher Ingeniure) 3957 Part 13, “Biological measurement procedures for determining and evaluating the effects of ambient air pollutions by means of lichens (bioindication). Mapping the diversity of epiphytic lichens as an indicator of air quality” (VEREIN DEUTSCHER INGENIEURE 2005).

The basis of the VDI-Guideline is that the diversity of epiphytic lichens is affected by atmospheric pollutants. A large diversity of species is desirable because it is an indication of favourable conditions for the survival of many species, including humans. However, intensive effects of abiotic factors, for instance nitrogen compounds or other pollutants with eutrophicating effects, may favour certain specialised species. Thus the increase of these specialised species must be evaluated negatively, since the factors which cause the increase of specialised species disturb the ecosystem. The parameter for estimating the level of environmental stress, which is a diversity value, is obtained by the number of lichen species and their frequency per area of the tree trunk (VEREIN DEUTSCHER INGENIEURE 2005).

Turning to epiphytic lichens, a succession has been caused by changing composition and intensity of air pollution during the last few decades. In the 1970s, $SO_2$ air pollution reached its peak. There were few acidophytes, no neutrophytes and hardly any species tolerant to these conditions. The pH values of naturally acidic, neutral or sub-neutral barks were significantly lowered. Since the 1980s, the concentration of acidic air pollutants has diminished and simultaneously there has been an increase in nitrogen compounds as well as airborne nutrients. This still leads to a corresponding increase in the numbers of lichen neutrophytes and indicators of eutrophication in trees with acidic barks. The pH values on acidic, neutral or sub-neutral barks still increases and this favours lichens which can handle such circumstances. Hence, acidophytes can hardly endure these conditions (VEREIN DEUTSCHER INGENIEURE 2005).

With regard to the VDI guideline, this means that the proportion of eutrophication indicators in the increase of lichen diversity is used as a negative factor for assessing air quality (VEREIN DEUTSCHER INGENIEURE 2005).

### 2.1 Sampling

Cities with an area of investigation between five and 100 square kilometres, should have sampling units with a side-length of 1 km. Consequently, the area of investigation consists of several sampling units. Within a sampling unit of one square kilometre, six to twelve trees shall be used for mapping (Fig. 1). These trees have to fulfil certain criteria and they should stand closest to the centre of the sampling unit. The trees should be equally distributed over the four partial quadrants. In a mapping project it is recommended to select trees of a single species, because the growing conditions of epiphytic lichens depend strongly on the age and shape of the trees as well as on bark properties. If this is not feasible, trees with similar bark properties such as pH value, nutrient content or water storage capability should be selected (Tab. 1) (VEREIN DEUTSCHER INGENIEURE 2005).

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**Tab. 1**: Tree species with similar physicochemical properties, which can be used interchangeably (tree circumference at a height of 1, 5 m) (Verein Deutscher Ingenieure 2005).

| Group I (the barks are sub-neutral under natural conditions) | Group II (the barks are ± acid under natural conditions) |
|---|---|
| *Acer platanoides* (70–280 cm) | *Alnus glutinosa* (70–280 cm) |
| *Fraxinus excelsior* (70–280 cm) | *Betula pendula* (70–280 cm) |
| *Ulmus* sp. (70–280 cm) | *Prunus avium* (70–280 cm) |
| *Juglans regia* (70–280 cm) | *Prunus domestica* (70–160 cm) |
| *Fraxinus ornus* (70–280 cm) | *Quercus robur* (70–280 cm) |
| *Populus × canadensis* agg. (70–280 cm) | *Quercus petraea* (70–280 cm) |
| *Acer pseudoplatanus* (70–280 cm) | *Pyrus communis* (70–160 cm) |
| *Malus domestica* (70–160 cm) | *Tilia cordata* (70–280 cm) |
| *Pyrus communis* (70–160 cm) | *Tilia platyphyllos* (70–280 cm) |
| *Tilia cordata* (70–280 cm) | |
| *Tilia platyphyllos* (70–280 cm) | |

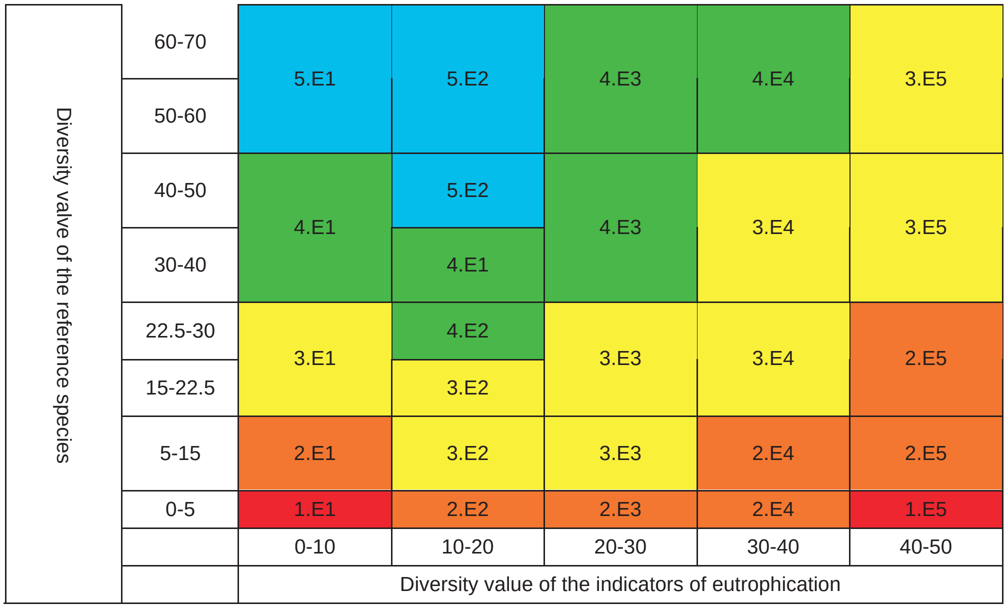


**Fig. 3**: Assessing air quality by combining the diversity values of the reference species and the diversity values of indicators of eutrophication (Verein Deutscher Ingenieure 2005).

With regard to the research carried out for this master thesis, a sampling unit of one square kilometre was chosen, in accordance with the size of Salzburg. There were 65 one square kilometre sampling units and 12 sampling units which had an area of less than one square kilometre due to the city limits of Salzburg. The trees chosen for the mapping belonged to Group II. For each tree, GPS coordinates were taken so that the trees can be found for subsequent studies.

Of course there are other modalities possible within the sampling. The sampling described above describes the method as it was used for this master thesis. For further information please see Verein Deutscher Ingenieure 2005.

### 2.1.1 Lichen recording on the tree trunk

As for the recording of lichens on the tree trunk, monitoring quadrates are used which consist of four independent segments with five squares 10 cm x 10 cm (Fig. 2). With the aid of a compass or GPS (Global Positioning System) the four segments are attached to the sides of the tree trunk facing the East, South, West and North. The segments have to be attached in a way that the lower edge is one metre above the highest point of the ground. Then, to avoid areas on the tree trunk that are unsuitable for the survey, for instance wounds and knots, a shifting of a segment by a maximum of 20° clockwise is permitted. Another tree has to be

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**Tab. 2**: Lichen species, which benefit from eutrophication/indicators of eutrophication (Verein Deutscher Ingenieure 2005).

| Species | Species |
|---|---|
| *Caloplaca citrina* (Hoffm.) Th. Fr. | *Physcia caesia* (Hoffm.) Fürnr. |
| *Caloplaca holocarpa* (Ehrh. ex Ach.) A.E. Wade | *Physcia dubia* (Hoffm.) Lettau |
| *Lecanora dispersa* (Pers.) Sommerf. | *Physcia tenella* (Scop.) DC. |
| *Lecanora hagenii* (Ach.) Ach. | *Physconia grisea* (Lam.) Poelt |
| *Lecanora muralis* (Schreb.) Rabenh. | *Rinodina* spp. |
| *Phaeophyscia nigricans* (Flörke) Moberg | *Xanthoria candelaria* (L.) Th. Fr. |
| *Phaeophyscia orbicularis* (Neck.) Moberg | *Xanthoris parietina* (L.) Th. Fr. |
| *Physcia adscendens* H. Olivier | *Xanthoria polycarpa* (Hoffm.) Th. Fr. ex Rieber |

**Tab. 3**: Summation of the lichen species frequencies on trees in a sampling unit (Verein Deutscher Ingenieure 2005).

| Tree | Lichen | Reference species | | | | Indicators of eutrophication | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | E | S | W | N | E | S | W |
| 1 | species 1 | 1 | 5 | 1 | 0 | | | | |
| 1 | species 2 | 3 | 4 | 1 | 3 | | | | |
| 1 | species 3 | 2 | 4 | 2 | 1 | | | | |
| 1 | species 4 | | | | | 2 | 4 | 1 | 3 |
| 1 | species 5 | | | | | 3 | 5 | 2 | 4 |
| 1 | species 6 | | | | | 1 | 3 | 0 | 0 |
| **1** | **Sum of frequencies tree 1** | **6** | **13** | **4** | **4** | **6** | **12** | **3** | **7** |
| 2 | species 1 | 1 | 0 | 5 | 3 | | | | |
| 2 | species 2 | 2 | 3 | 2 | 2 | | | | |
| 2 | species 3 | 1 | 1 | 1 | 1 | | | | |
| 2 | species 4 | | | | | 5 | 2 | 5 | 2 |
| 2 | species 5 | | | | | 4 | 1 | 5 | 3 |
| 2 | species 6 | | | | | 3 | 3 | 4 | 2 |
| **2** | **Sum of frequencies tree 2** | **4** | **4** | **8** | **6** | **12** | **6** | **14** | **7** |

**Tab. 4**: In a sampling unit g the lichen diversity value is calculated for reference species and indicators of eutrophication from the sum of frequencies (Verein Deutscher Ingenieure 2005).

| Tree | | Reference species | | | | Indicators of eutrophication | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | E | S | W | N | E | S | W |
| 1 | Sum of frequencies tree 1 | 6 | 13 | 4 | 4 | 6 | 12 | 3 | 7 |
| 2 | Sum of frequencies tree 2 | 4 | 4 | 8 | 6 | 12 | 6 | 14 | 7 |
| **Mean sums of frequencies of the sampling area g** | | **5** | **8,5** | **6** | **5** | **9** | **9** | **8,5** | **7** |
| **Lichen diversity value of the sampling unit g** | | **24,5** | | | | **33,5** | | | |

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selected if the placement of at least three segments is impossible. If conditions such as damaged or decorticated parts, knots, rain tracks and parts with bryophyte cover higher than 25 % the attachment of segments is prohibited, but muscicolous lichens are included in the calculation of the diversity. If the mapping is to be repeated precisely it is advisable to mark the location of the segments durably. Then the lichen species which occur in each segment are recorded, as well as the number of squares of each segment in which the lichen species was found. This is called frequency and it is the basis of the quantitative survey of the lichen vegetation. One is not allowed to take away lichens from within the monitoring quadrate if repetition of the survey is planned (Verein Deutscher Ingenieure 2005).

## 2.2 Determining the air quality index by data analysis

The air quality index is composed of the diversity of the lichen population and the frequency of each species in a sampling area. Diversity is defined as the number of species found in a certain area and it is used as a quality criterion. The VDI guideline uses the diversity weighted by frequency as a measure of air quality. In a sampling unit, the weighted diversity is called lichen diversity value (LDV) and is used as a statistical estimate of the air quality conditions. Different effects of eutrophicating and non-eutrophicating air pollutants on the occurrence of lichens have been recognized. Therefore the lichen diversity values of species which respond positively ("indicators of eutrophication", Tab. 2) and of species which respond negatively to eutrophication are calculated separately. "Reference species" is the term used for lichens which respond negatively to eutrophication. The air quality index is formed out of the two lichen diversity values of a unit, and the air quality index is then used as a measure of the air quality in a sampling unit (Verein Deutscher Ingenieure 2005).

### 2.2.1 Calculation of the lichen diversity value

First, the frequencies of the different lichen species are summed up separately for eutrophication and reference species, as well as for each compass direction for the trees in a sampling unit (Tab. 3). For each compass point, the average of the sums of frequencies of all trees of a sampling unit is calculated. Then the averages of the frequency sums are added up to form the lichen diversity values of the indicators of eutrophication and of the reference species (Tab. 4). At the end of the calculation there are two lichen diversity values, which are necessary for data interpretation (Verein Deutscher Ingenieure 2005).

### 2.2.2 Data interpretation

The termini "very high – high – moderate – low – very low" are used to describe the air quality of a sampling unit. A specific colour is assigned to each air quality class for cartographic presentation.

Air quality is evaluated by entering the diversity value of the indicators of eutrophication along the abscissa, and the diversity value of the reference species along the ordinate of an evaluation matrix (Fig. 3). The crossing point of the lichen diversity values shows the evaluation of the air quality of the sampling unit. Information on air quality is given by indices in this evaluation matrix. An index is composed of two digits separated by the letter E, which stands for indicators of eutrophication. The first digit represents the overall air quality (Tab. 5) whereas the second digit with the "E" is directly related to the diversity of the indicators of eutrophication (Tab. 6) (Verein Deutscher Ingenieure 2005).

## 3. Results & Discussion

### 3.1 List of species

The list of species does not claim to be complete, as the aim of this study was not to count all lichen species occurring in Salzburg. The lichen species identified in this study were obtained according to the VDI Guideline for determining and evaluating the effects of ambient air pollution by means of lichens (bioindication). According to Ellenberg et al. (1992), indicator values are shown for each species occurring in this study (Tab. 7). A percentage value shows the relative frequency in the study area per tree trunk segments (Tab. 8). The species *Phaeophyscia hirsuta* was recorded for the first time in the city zone of Salzburg.

### 3.2 Discussion of Lichen Species

The most frequent lichens occurring in the present study are *Candelaria concolor, Candelariella reflexa, Candelariella xanthostigma, Lepraria* sp., *Parmelia sulcata, Phaeophyscia orbicularis, Phlyctis argena, Physcia adscendens and Physcia tenella* (Tab. 8).

❖ ***Candelaria concolor* (Dicks.) Stein**

This lichen occurred on 9,28 % of all tree trunk segments. Its reaction number is 6, which means that this species likes a pH value between 5 and 7. Although Ellenberg et al. 1992 stated that the range around neutrality point till the basic range is not enough differentiated for lichens. Its nutrient number is 6, which means that the species' preferred bark properties lie between mineral rich and nutrient rich dust as well as moderate impregnation with nutrient rich dust and frequent dust impregnation and moderate fertilisation by animals. Toxitolerance number is 4. This means that its tolerance towards toxic substances like air pollutants is average. *Candelaria concolor* mostly lives on sub-neutral barks that are rich in minerals and often dust impregnated, on free standing deciduous trees, alley trees and in orchards (Ellenberg et al. 1992; Wirth 1995; Kirschbaum & Wirth 1997).

❖ ***Candelariella reflexa* (Nyl.) Lettau**

*Candelariella relfexa* is found on 8,73 % of total tree trunk segments. The reaction number is five, which means that the

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**Tab. 5**: Relation of the evaluation of air quality, the first digit of the air quality index and the colour for cartographic presentation (VEREIN DEUTSCHER INGENIEURE 2005).

| Evaluation of air quality | Index value (first digit) and colour |
|---|---|
| Very high air quality | 5 |
| High air quality | 4 |
| Moderate air quality | 3 |
| Low air quality | 2 |
| Very low air quality | 1 |

**Tab. 6**: Relation of the diversity values of the indicators for eutrophication, the influence of eutrophicating substances and the second digit of the air quality index (VEREIN DEUTSCHER INGENIEURE 2005).

| Diversity values of the indicators for eutrophication | Influence of eutrophicating substances | Index value (second digit) |
|---|---|---|
| Very high | Very strong | E5 |
| High | Strong | E4 |
| Moderate | Moderate | E3 |
| Low | Low | E2 |
| Very low | Very low | E1 |

lichen is found on moderate acid barks between a pH value of 4,9 – 5,6. Nutrient number is five and toxitolerance is 4. Therefore this lichen has the same requirements as *Candelaria concolor* in the two aspects mentioned before. This lichen often occurs on nutrient rich, mineral rich, sub-neutral barks mostly located at the basis of tree trunks (ELLENBERG et al. 1992; WIRTH 1995; KIRSCHBAUM & WIRTH 1997).

These two lichen species all prefer sub-neutral bark conditions according to WIRTH 1995. With regard to their indicator values (ELLENBERG et al. 1992) rather slightly acidic barks. This is a very interesting, though also slightly controversial aspect. The trees used for this study do have a more or less acidic bark under natural conditions. A reason for their abundant number can be the high nitrogen dioxide values measured by the government of Salzburg by technical measurements. The abundant nitrogen values are obviously altering the bark conditions of the trees from more or less acidic to rather sub-neutral conditions. Regarding their abundance, perhaps the lichens prefer slightly less acidic conditions than is described in the indicator values, or otherwise the pH value of the trees are directly in the pH range of the lichens.

### ❖ *Candelariella xanthostigma* (ACH.) LETTAU

*Candelariella xanthostigma* is the most abundant lichen in the investigation with 34,26 % of total tree trunk segments. The reaction number is five, which means that the lichen is found on moderately acidic barks between a pH value of 4,9 – 5,6. This corresponds with the bark properties of the trees used for the mapping. The nutrient number is 4, which means that this species prefers barks with a medium mineral content, not moderate and not rich in minerals. The same properties apply to eutrophication. *Candelariella xanthostigma* has a higher toxitolerance than *Candelaria concolor* and *Candelariella reflexa*, namely 6, which means moderately high toxitolerance. *Candelariella xanthostigma* is found up until high montane regions, predominantly on deciduous trees. The lichen is relatively euryoecious. Notably, barks of medium acidity and eutrophication are preferred (ELLENBERG et al. 1992; WIRTH 1995; KIRSCHBAUM & WIRTH 1997).

The high abundance of the lichen is probably due to its being euryoecious. It has a very wide range where it can live optimally. Its preferred pH value range meets the bark properties of the trees used for mapping, and the nutrient number seems to be appropriate as well.

### ❖ *Lepraria* sp.

It is very difficult to determine the correct species, thus only the genus was recorded during the mapping. Therefore no indicator values are present. *Lepraria* sp. is the second most abundant lichen recorded with 24,33 % of total tree trunk segments. *Lepraria* sp. seems to be very tolerant towards air pollution.

### ❖ *Parmelia sulcata* TAYLOR

*Parmelia sulcata* was found on 7,45 % of total tree trunk segments. The reaction number is five, which means that the lichen prefers moderately acidic conditions with a pH value between 4,9 and 5,6. *Parmelia sulcata* has the same nutrient number as *Candelariella xanthostigma* and therefore has the same requirements regarding nutrient content. Toxitolerance is very high, namely 8. This is the second highest value possible. *Parmelia sulcata* is found up until high montane regions on barks of deciduous trees. This lichen does have a very broad ecological amplitude and is therefore one of the most abundant

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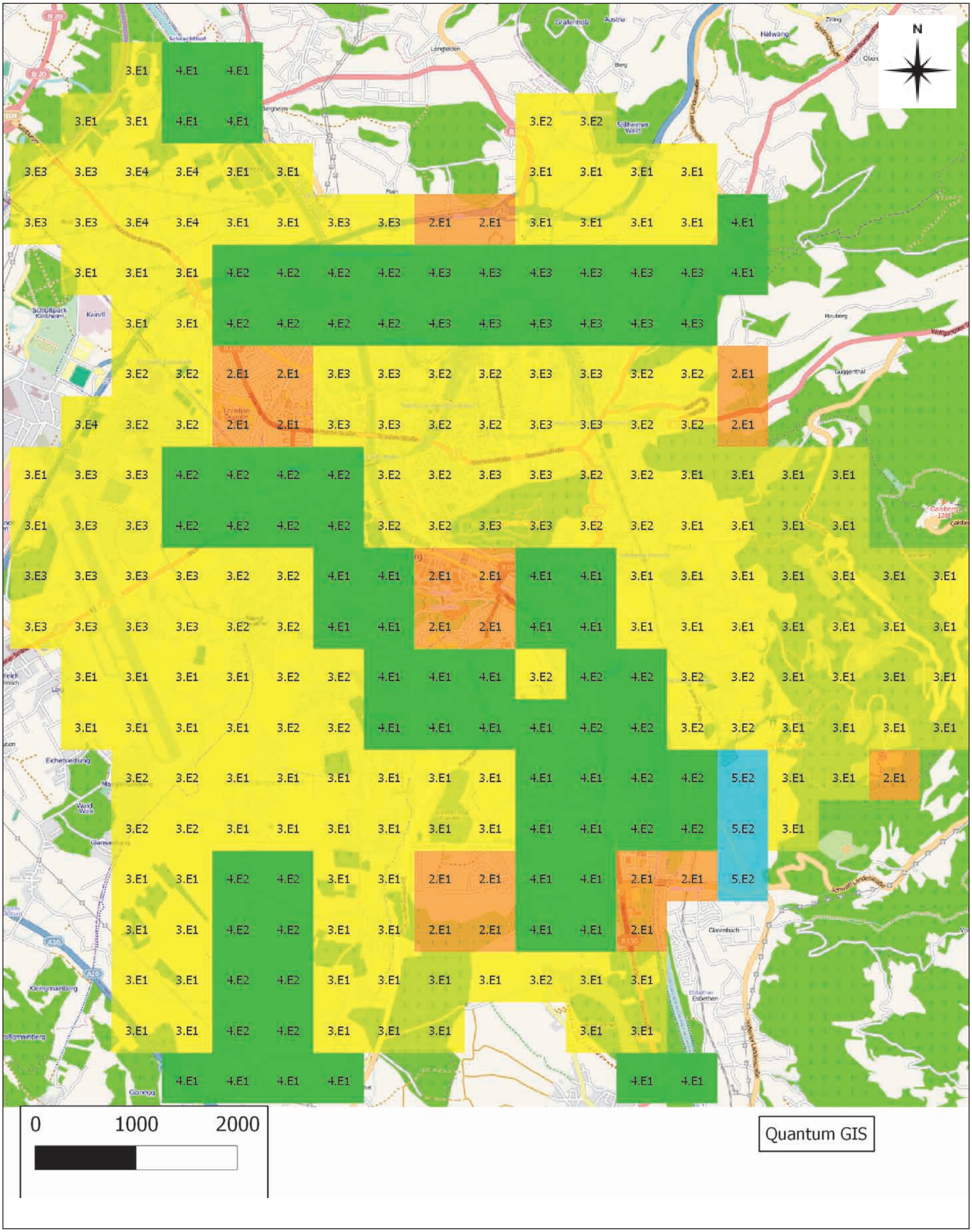


**Fig. 4**: Map 1 of air quality according to Verein Deutscher Ingenieure 2005.

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**Tab. 7**: Lichens and their indicator values (Ellenberg et al. 1992).

| Species | Reaction number | Nutrient number | Toxitolerance |
|---|---|---|---|
| *Amandinea punctata* (Hoffm.) Coppins & Scheid. | 5 | 5 | 9 |
| *Candelaria concolor* (Dicks.) Stein | 6 | 5 | 4 |
| *Candelariella reflexa* (Nyl.) Lettau | 5 | 5 | 4 |
| *Candelariella xanthostigma* (Ach.) Lettau | 5 | 4 | 6 |
| *Cladonia coniocraea* (Flörke) Spreng. | 4 | 2 | |
| *Cladonia fimbriata* (L.) Fr. | 4 | 1 | |
| *Cladonia* sp. | | | |
| *Flavopunctelia flaventior* (Stirt.) Hale | 4 | 5 | 6 |
| *Graphis scripta* (L.) Ach. | 5 | 3 | 5 |
| *Hypogymnia farinacea* Zopf | 3 | 2 | 6 |
| *Hypogymnia physodes* (L.) Nyl. | 3 | 2 | 8 |
| *Hypogymnia tubulosa* (Schaer.) Hav. | 3 | 3 | 6 |
| *Hypotrachyna revoluta* (Flörke) Hale | 3 | 3 | 4 |
| *Imshaugia aleurites* (Ach.) S. L.F. Meyer | 2 | 1 | 4 |
| *Lecania cyrtella* (Ach.) Th. Fr. | 7 | 5 | 3 |
| *Lecanora argentata* (Ach.) Malme | 5 | 3 | 4 |
| *Lecanora chlarotera* Nyl. | 6 | 4 | 6 |
| *Lecanora hagenii* (Ach.) Ach. | 8 | 6 | 8 |
| *Lecanora subrugosa* Nyl. | | | |
| *Lecidella elaeochroma* (Ach.) M. Choisy | 6 | 4 | 6 |
| *Lepraria* sp. | | | |
| *Melanelixia fuliginosa ssp. glabratula* (Lamy) J.R. Laundon | 3 | 3 | 6 |
| *Melanohalea elegantula* (Zahlbr.) O. Blanco et al. | 4 | 3 | 4 |
| *Melanohalea exasperatula* (Nyl.) O. Blanco et al. | 5 | 4 | 6 |
| *Normandina pulchella* (Borrer) Nyl. | 5 | 4 | 4 |
| *Parmelia saxatilis* (L.) Ach. | 3 | 2 | 7 |
| *Parmelia sulcata* Taylor | 5 | 4 | 8 |
| *Parmelina tiliacea* (Hoffm.) Hale | 5 | 4 | 5 |
| *Parmeliopsis hyperopta* (Hoffm.) Hale | 2 | 2 | |
| *Pertusaria albescens* (Huds.) M. Choisy & Werner var. *albescens* | 6 | 4 | 4 |
| *Phaeophyscia endophoenicea* (Harm.) Moberg | 7 | 5 | 3 |
| *Phaeophyscia hirsuta* (Mereschk.) Essl. | | | |
| *Phaeophyscia orbicularis* (Neck.) Moberg | 7 | 7 | 7 |
| *Phlyctis argena* (Spreng.) Flot. | 5 | 3 | 6 |
| *Physcia adscendens* H. Olivier | 7 | 6 | 8 |
| *Physcia caesia* (Hoffm.) Fürnr. var. *caesia* | 8 | 8 | |
| *Physcia stellaris* (L.) Nyl. | 6 | 5 | 4 |
| *Physcia tenella* (Scop.) DC. | 6 | 6 | 8 |
| *Physconia distorta* (With.) J.R. Laundon | 7 | 6 | 3 |
| *Physconia grisea* (Lam.) Poelt | 7 | 7 | 7 |
| *Physconia perisidiosa* (Erichsen) Moberg | 6 | 4 | 4 |
| *Protoparmelia hypotremella* Herk, Spier & V. Wirth | | | |
| *Pseudevernia furfuracea* (L.) Zopf var. *furfuracea* | 2 | 1 | -7 |
| *Punctelia subrudecta* (Nyl.) Krog | 4 | 3 | 6 |
| *Punctelia ulophylla* (Ach.) Herk & Aptroot | | | |
| *Ramalina farinacea* (L.) Ach. var. *farinacea* | 5 | 3 | 6 |
| *Ropalospora viridis* (Tønsberg) Tønsberg | 4 | 3 | 5 |
| *Scoliciosporum chlorococcum* (Graewe ex Stenh.) Vězda | 3 | 5 | 8 |
| *Trapeliopsis flexuosa* (Fr.) Coppins & P. James | | | |
| *Usnea* sp. | | | |
| *Vulpicida pinastri* (Scop.) J.-E. Mattsson & M.J. Lai | 2 | 1 | 4 |
| *Xanthomendoza fallax* (Hepp) Søchting, Kärnefelt & S. Kondr. | 7 | 5 | 5 |
| *Xanthoria candelaria* (L.) Th. Fr. | 6 | 7 | 5 |
| *Xanthoria parietina* (L.) Th. Fr. | 7 | 6 | 7 |
| *Xanthoria polycarpa* (Hoffm.) Th. Fr. ex Rieber | 6 | 6 | 7 |

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and toxitolerant lichens. Although, in this study, this lichen species is not as abundant as it should be according to the literature (ELLENBERG et al. 1992; WIRTH 1995; KIRSCHBAUM & WIRTH 1997).

❖ ***Phaeophyscia orbicularis* (NECK.) MOBERG**

*Phaeophyscia orbicularis* occurs on 10,48 % of total tree trunk segments. This lichen has a reaction number of 7, which means that it prefers subneutral conditions with a pH value between 5,7 and 6,5. The nutrient number is also 7. Hence the lichen prefers nutrient rich habitats, frequent impregnation with dust or moderate fertilisation by animals. Toxitolerance is 7, considerable high tolerance. With regard to the reaction number and trees used for the recording, it seems obvious that this lichen can only occur on trees which have been subject to eutrophication, because otherwise the pH value of the tree barks would have been too low. *Phaeophyscia orbicularis is* a euryoecious and eutrophication tolerant species. Without eutrophication, the lichen can only occur on subneutral barks of deciduous trees (ELLENBERG et al. 1992; WIRTH 1995; KIRSCHBAUM & WIRTH 1997).

❖ ***Phlyctis argena (SPRENG.) FLOT.***

*Phlyctis argena* is found on 8,05 % of total tree trunk segments. Reaction number is 5 which means that it prefers moderately acidic conditions with a pH value between 4,9 and 5,6. Nutrient number is three, thus this lichen prefers moderate mineral rich barks with no or very low eutrophication. Toxitolerance is 6, which means moderate high toxitolerance. *Phlyctis argena* is found up until high montane regions, mostly on deciduous trees and conifers. This lichen is euryoecious and its pH value range meets the bark properties of the trees used for lichen recording. Although this lichen is very abundant in forests, it is not as abundant in Salzburg maybe because of eutrophication due to high nitrogen dioxide values (ELLENBERG et al. 1992; WIRTH 1995; KIRSCHBAUM & WIRTH 1997).

❖ ***Physcia adscendens* H. OLIVIER**

*Physcia adscendens* occurs on 14,76 % of total tree trunk segments. Reaction number is 7, which means that the lichen prefers subneutral conditions with a pH value between 5,7 and 6,5. Nutrient number is 6, which means that preferred bark properties lie between mineral rich and nutrient rich dust as well as moderate impregnation with nutrient rich dust and frequent dust impregnation and moderate fertilisation by animals. Toxitolerance is 8, which is high. The relatively high pH value range leads to the assumption that the high nitrogen dioxide values in Salzburg are responsible for less acidic bark conditions. *Physcia adscendens* occurs up until montane regions and is often found on nutrient rich and eutrophicated locations. The lichen is relatively toxitolerant and is able to invade foliose lichen poor regions (ELLENBERG et al. 1992; WIRTH 1995).

❖ ***Physcia tenella (SCOP.) DC.***

*Physcia tenella* is the third most abundant lichen species in this investigation; it covers 21,80 % of total tree trunk segments. Its reaction number is 6, which means that the lichen likes a pH value between 5 and 7. This lichen has the same nutrient number and therefore requirements for nutrient content as *Physcia adscendens*. *Physcia tenella* has a high toxitolerance, namely 8. *Physcia tenella* is often socialized with *Physcia adscendens* although *Physcia tenella* prefers a bit more acidic habitats and is a bit more toxitolerant. Again, the high nitrogen dioxide values may be a reason for the high abundance of this lichen because the trees on which the lichen species were recorded have a more or less acidic bark. Whereas *Physcia tenella* prefers rather alkaline barks, the trees used for recording look altered to more alkaline bark properties by air pollution (ELLENBERG et al. 1992; WIRTH 1995).

## 3.3 Map 1 of air quality according to VDI 3957 Part 13

### 3.3.1 Discussion of Map 1 (Fig. 4)

There are three main factors which contribute to lichen distribution in cities: water balance, heat regulation and air pollution. In cities like Salzburg the natural soil is sealed up with various materials like asphalt, concrete and stone. Therefore there is less soil moisture. Nevertheless there is a lot of rainfall in Salzburg and the city is a humid biotope. Therefore Salzburg is a good site for lichen growth. Regarding air pollution, emissions lead to less transmission which leads to a rise in temperature and as a consequence there is less dewfall. Air pollution is said to have the highest impact on lichens in terms of health. Especially weather inversions lead to a high concentration of pollutants. Inversions occur very often in Salzburg but there is no lack of trees (STÜBER 1975). Trees are distributed relatively evenly in the city. In the city zone of Salzburg, moderate air quality prevails (62,8 %). High air quality was found in 26,9 % of the investigation area.

❖ **2.E1**

2.E1 is the worst air quality detected in Salzburg. It means low air quality with very low diversity values of the indicators for eutrophication and very low influence of eutrophicating substances. Seven Sampling units have this air quality and they are spread all over the city. A low number of lichen frequencies characterize this air quality. Although there is a low influence and diversity value of the indicators of eutrophication, this does not mean that air quality is therefore better. As the first digit indicates, the overall air quality is low. Accordingly, this indicates that pollutant levels are so high that neither lichens specialized for acidic situations, nor lichens specialized for eutrophication, nor lichens with medium specialization are able to grow properly. Low air quality was also detected in the inner city between the Kapuzinerberg and the Mönchs- Rainberg. A reason could be the high percentage of sealed area in this district as well as the distinctive weather inversions there. To the north-west there is another sampling unit with low air quality which may also be due to a high percentage of sealed up area as well as the proximity of a thermal power station. To the north, the low air quality area lies directly south of the motorway. The other locations of low air quality may be due to the transport of air pollutants.

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❖ **3.E1**

This air quality was detected in 28 sampling units and is by far the most frequently occurring air quality in Salzburg. It covers 35,9 % of Salzburg. 3.E1 means moderate air quality with very low diversity values of the indicators for eutrophication and a very low influence of eutrophicating substances. 3.E1 mainly occurs in the periphery of Salzburg. To the east, at the Gaisberg, this air quality prevails. But also to the south, where air quality seems to get better, moderate air quality is abundant. Moderate air quality stretches also a bit to the west and to the north, but this air quality is not found in the inner parts of Salzburg. There is one pattern which all sampling units with air quality 3.E1 have in common, namely that the area is not heavily built up.

❖ **3.E2**

In 11 sampling units (14,1 %) this air quality was detected. It means moderate air quality with low diversity values of the indicators for eutrophication and low influence of eutrophicating substances. Especially in the mid north the area where this air quality occurs is heavily built up and close to big streets. To the south-west the area is not as heavily built up as in the mid north.

❖ **3.E3**

This air quality occurred in 8 sampling units (10,3 %). This means moderate air quality with moderate diversity of the indicators for eutrophication and moderate influence of eutrophicating substances. To the north mid-north, this air quality was found directly next to the motorway, as well as near a big through street. To the west, this air quality was evaluated in the vicinity of the airport. The exhaust emissions of the aeroplanes and cars on the big through street may be a reason for the rise in the eutrophication value.

❖ **3.E4**

This air quality was detected in two sampling units (2,6 %). This means moderate air quality with high diversity values of the indicators for eutrophication and strong influence of eutrophicating substances. One sampling unit with this air quality was in the north near a through road and near train tracks. The other sampling unit was in the direct vicinity of the motorway. The location of these sampling units near traffic routes could perhaps explain their higher eutrophication values.

❖ **4.E1**

This air quality was detected in 10 sampling units (12,8 %). 4.E1 means high air quality with very low diversity values of the indicators for eutrophication and very low influence of eutrophicating substances. The sampling units with this air quality were mostly situated between the centre and the south of Salzburg. These sampling units are characterized by having a lot of green areas, as does the sampling unit in the north. Although the “Alpenstraße” goes through some of the units, the area has relatively good air quality. A possibile explanation for the high air quality may be that the exhausts from the “Alpenstraße” are blown away to other parts of Salzburg.

❖ **4.E2**

The air quality 4.E2 was detected in eight sampling units which means a percentage cover of 10,3 %. This means high air quality with low diversity values of the indicators for eutrophication and low influence of eutrophicating substances. There are less sampling units with air quality 4.E2 than with 4.E1. 4.E2 can be found in relatively green areas, like in the vicinity of the river Glan, as well as in more built up areas. The higher eutrophication level compared to 4.E1 may be due to winds which can move air pollutants around, because there is no constant pattern visible.

❖ **4.E3**

The air quality 4.E3 only occurred in three sampling units which means a coverage of 3,8 %. It means high air quality with moderate diversity values of the indicators for eutrophication and moderate influence of eutrophicating substances. This air quality was only found in the north of Salzburg beyond the motorway which is perhaps an explanation for the higher eutrophication level. The area is not heavily built up so there must be exhausts from somewhere else affecting the lichens.

❖ **5.E2**

This air quality only occurred in one sampling unit and therefore has a very small coverage percentage of 1,3 %. 5.E2 represents very high air quality with low diversity values of the indicators for eutrophication and low influence of eutrophicating substances. The sampling unit is located to the south-east of Salzburg and lies in a moderately built up area.

## 3.4 Comparison of air quality indices and technical measurement

Technical measurements obtain quantitative data for selected pollutants at a distinctive time and place. The effects of air pollutants on humans and nature can only be estimated. Therefore bioindication is a good tool to determine the effects of a mixture of air pollutants on living things, although only a rough estimation of air pollution can be drawn. Furthermore, lichen mapping shows the effects of all air pollutants on lichens over a longer period. Hence these two methods complement each other very well (Franzen et al. 2002)

Tab. 9 shows health threshold values for air pollutants obtained by technical measurements.

Tab. 10 shows data of air pollutants in Salzburg and their corresponding air quality index. Due to the complex calculation of the air quality index, a comparison is only made between the air pollutant data obtained by technical measurement and the air quality index obtained by the VDI method (Tab. 10).

In the first half of the year 2009, Rudolfsplatz had the highest nitrogen dioxide values compared to Mirabellplatz and Lehen; no sulphur dioxide values are available for Rudolfsplatz. The values for particular matter are in the range of Mirabellplatz and Lehen. According to the lichen mapping carried out during this study, the worst air quality was also detected at Rudolfsplatz. In the case of Rudolfsplatz, the high nitrogen dioxide values seem

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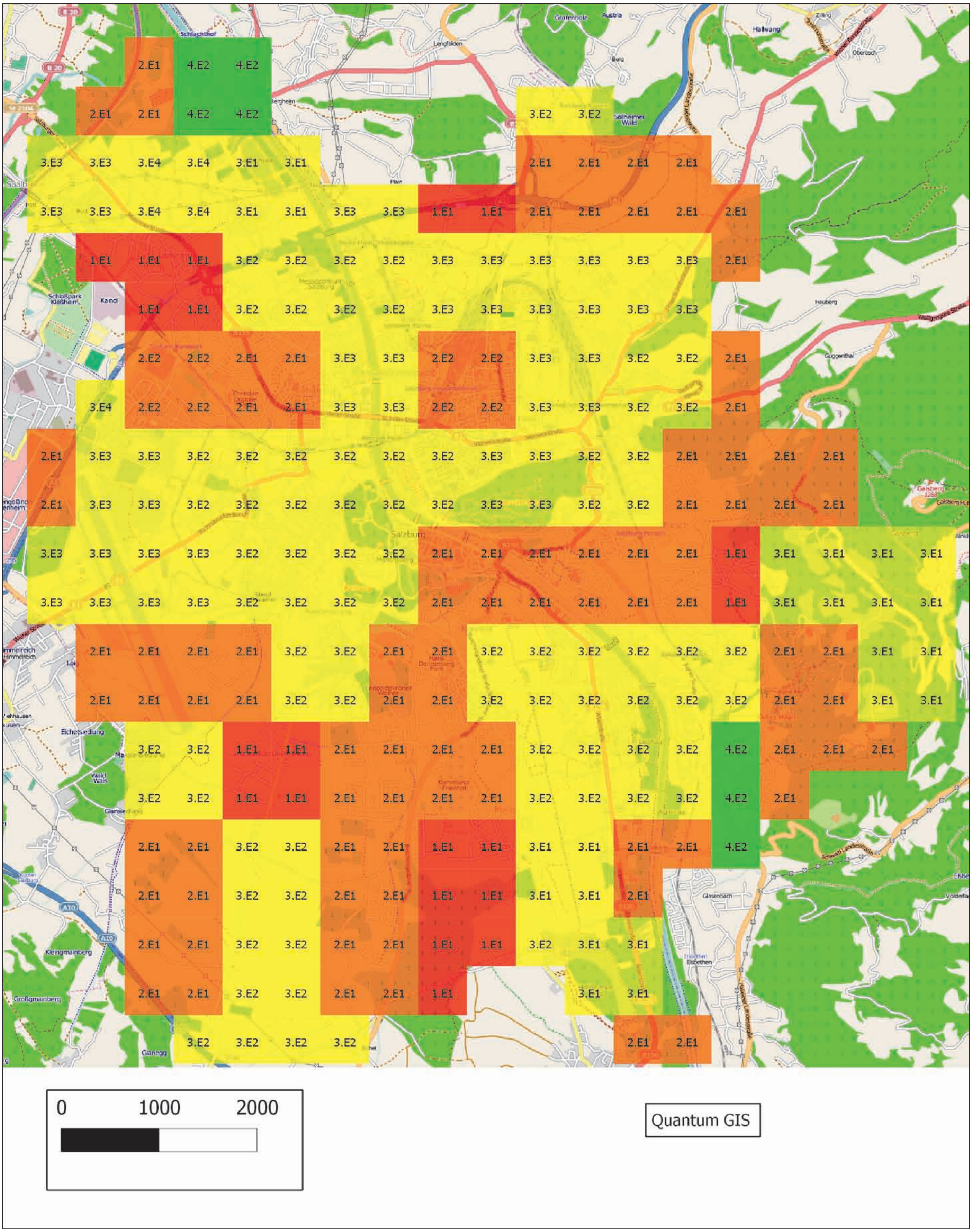


**Fig. 5**: Recalculation of the air quality indices, Map 2

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**Tab. 8**: Lichen species and their relative frequency (percentage value).

| Species | Percent of total tree trunk segments south in % | Percent of total tree trunk segments west in % | Percent of total tree trunk segments north in % | Percent of total tree trunk segments east in % | Percent of total tree trunk seg-ments in % |
|---|---|---|---|---|---|
| *Amandinea punctata* (HOFFM.) COPPINS & SCHEID. | *3,14* | *1,55* | *1,05* | *1,86* | *1,90* |
| *Candelaria concolor* (DICKS.) STEIN | ***12,18*** | ***9,82*** | ***7,18*** | ***7,95*** | ***9,28*** |
| *Candelariella reflexa* (NYL.) LETTAU | ***6,59*** | ***9,36*** | ***9,09*** | ***9,86*** | ***8,73*** |
| *Candelariella xanthostigma* (ACH.) LETTAU | ***37,95*** | ***33,50*** | ***28,50*** | ***37,09*** | ***34,26*** |
| *Cladonia coniocraea* (FLÖRKE) SPRENG. | *0,55* | *1,36* | *1,45* | *0,82* | *1,05* |
| *Cladonia fimbriata* (L.) FR. | *0,05* | *0,14* | *0,27* | *0,00* | *0,11* |
| *Cladonia* sp. | *0,00* | *0,23* | *0,23* | *0,23* | *0,17* |
| *Flavopunctelia flaventior* (STIRT.) HALE | *0,45* | *0,27* | *0,05* | *0,05* | *0,20* |
| *Graphis scripta* (L.) ACH. | *0,05* | *0,14* | *0,23* | *0,00* | *0,10* |
| *Hypogymnia farinacea* ZOPF | *0,00* | *0,00* | *0,00* | *0,05* | *0,01* |
| *Hypogymnia physodes* (L.) NYL. | *1,77* | *2,77* | *2,82* | *2,27* | *2,41* |
| *Hypogymnia tubulosa* (SCHAER.) HAV. | *0,05* | *0,00* | *0,00* | *0,05* | *0,02* |
| *Hypotrachyna revoluta* (FLÖRKE) HALE | *0,05* | *0,00* | *0,00* | *0,00* | *0,01* |
| *Imshaugia aleurites* (ACH.) S. L.F. MEYER | *0,00* | *0,00* | *0,00* | *0,05* | *0,01* |
| *Lecania cyrtella* (ACH.) TH. FR. | *0,00* | *0,00* | *0,09* | *0,00* | *0,02* |
| *Lecanora argentata* (ACH.) MALME | *0,00* | *0,00* | *0,05* | *0,00* | *0,01* |
| *Lecanora chlarotera* NYL. | *0,82* | *2,14* | *1,68* | *1,09* | *1,43* |
| *Lecanora hagenii* (ACH.) ACH. | *0,00* | *0,00* | *0,09* | *0,00* | *0,02* |
| *Lecanora subrugosa* NYL. | *0,14* | *0,00* | *0,23* | *0,09* | *0,11* |
| *Lecidella elaeochroma* (ACH.) M. CHOISY | *0,95* | *1,50* | *0,91* | *0,59* | *0,99* |
| *Lepraria* sp. | ***20,45*** | ***22,32*** | ***28,41*** | ***26,14*** | ***24,33*** |
| *Melanelixia fuliginosa* ssp. *glabratula* (LAMY) J.R. LAUNDON | *0,27* | *0,73* | *0,50* | *0,27* | *0,44* |
| *Melanohalea elegantula* (ZAHLBR.) O. BLANCO et al. | *0,00* | *0,00* | *0,09* | *0,27* | *0,09* |
| *Melanohalea exasperatula* (NYL.) O. BLANCO et al. | *4,64* | *6,14* | *5,68* | *5,73* | *5,55* |
| *Normandina pulchella* (BORRER) NYL. | *0,00* | *0,50* | *1,05* | *0,77* | *0,58* |
| *Parmelia saxatilis* (L.) ACH. | *0,18* | *0,23%* | *0,41* | *0,05* | *0,22* |
| *Parmelia sulcata* TAYLOR | ***6,50*** | ***7,82*** | ***8,09*** | ***7,41*** | ***7,45*** |
| *Parmelina tiliacea* (HOFFM.) HALE | *2,41* | *1,59* | *1,68* | *2,05* | *1,93* |
| *Parmeliopsis hyperopta* (HOFFM.) HALE | *0,14* | *0,00* | *0,00* | *0,00* | *0,03* |
| *Pertusaria albescens* (HUDS.) M. CHOISY & WERNER var. *albescens* | *0,50* | *0,55* | *0,45* | *0,23* | *0,43* |
| *Phaeophyscia endophoenicea* (HARM.) MOBERG | *1,27* | *0,95* | *0,41* | *0,91* | *0,89* |
| *Phaeophyscia hirsuta* (MERESCHK.) ESSL. | *0,00* | *0,00* | *0,00* | *0,05* | *0,01* |
| *Phaeophyscia orbicularis* (NECK.) MOBERG | ***11,91*** | ***10,50*** | ***9,05*** | ***10,45*** | ***10,48*** |
| *Phlyctis argena* (SPRENG.) FLOT. | ***7,00*** | ***8,82*** | ***8,00*** | ***8,36*** | ***8,05*** |
| *Physcia adscendens* H. OLIVIER | ***13,09*** | ***16,14*** | ***13,64*** | ***16,18*** | ***14,76*** |
| *Physcia caesia* (HOFFM.) FÜRNR. var. *caesia* | *0,05* | *0,09* | *0,27* | *0,23* | *0,16* |
| *Physcia stellaris* (L.) NYL. | *0,05* | *0,05* | *0,05* | *0,00* | *0,03* |
| *Physcia tenella* (SCOP.) DC. | ***21,36*** | ***23,55*** | ***21,18*** | ***21,09*** | ***21,80*** |
| *Physconia distorta* (WITH.) J.R. LAUNDON | *0,00* | *0,00* | *0,05* | *0,00* | *0,01* |
| *Physconia grisea* (LAM.) POELT | *0,00* | *0,05* | *0,00* | *0,00* | *0,01* |
| *Physconia perisidiosa* (ERICHSEN) MOBERG | *0,05* | *0,05* | *0,00* | *0,00* | *0,02* |
| *Protoparmelia hypotremella* HERK, SPIER & V. WIRTH | *0,00* | *0,09* | *0,27* | *0,05* | *0,10* |
| *Pseudevernia furfuracea* (L.) ZOPF var. *furfuracea* | *0,14* | *0,00* | *0,05* | *0,18* | *0,09* |
| *Punctelia subrudecta* (NYL.) KROG | *2,18* | *2,00* | *2,32* | *1,86* | *2,09* |
| *Punctelia ulophylla* (ACH.) HERK & APTROOT | *0,23* | *0,09* | *0,50* | *0,18* | *0,25* |
| *Ramalina farinacea* (L.) ACH. var. *FARINACEa* | *0,05* | *0,00* | *0,05* | *0,09* | *0,05* |
| *Ropalospora viridis* (TØNSBERG) TØNSBERG | *0,23* | *0,86* | *0,82* | *0,68* | *0,65* |
| *Scoliciosporum chlorococcum* (GRAEWE EX STENH.) VĚZDA | *0,00* | *0,00* | *0,05* | *0,00* | *0,01* |
| *Trapeliopsis flexuosa* (FR.) COPPINS & P. JAMES | *0,00* | *0,00* | *0,00* | *0,05* | *0,01* |
| *Usnea* sp. | *0,18* | *0,00* | *0,14* | *0,09* | *0,10* |
| *Vulpicida pinastri* (SCOP.) J.-E. MATTSSON & M.J. LAI | *0,00* | *0,23* | *0,00* | *0,00* | *0,06* |
| *Xanthomendoza fallax* (HEPP) SØCHTING, KÄRNEFELT & S. KONDR. | *1,36* | *1,23* | *0,68* | *1,32* | *1,15* |
| *Xanthoria candelaria* (L.) TH. FR. | *0,23* | *0,05* | *0,00* | *0,23* | *0,13* |
| *Xanthoria parietina* (L.) TH. FR. | *2,91* | *4,09* | *3,55* | *4,14* | *3,67* |
| *Xanthoria polycarpa* (HOFFM.) TH. FR. EX RIEBER | *0,00* | *0,05* | *0,05* | *0,05* | *0,03* |

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to be responsible for the low air quality. Since 1998, the annual mean nitrogen dioxide values have exceeded the health threshold values. A reason for the low air quality index and the high pollutant value may be the high volume of traffic at Rudolfsplatz. Furthermore, at Rudolfsplatz three very toxitolerant species, *Phaeophyscia orbicularis, Physcia adscendens* and *Physcia tenella* were abundant, but only on one tree. The other trees were more or less free of lichens, which hints at the rather low air quality. Overall, a relationship between the amount of measured pollutants and air quality index can be seen.

At Lehen and Mirabellplatz, according to the lichen mapping there is moderate air quality but Lehen has a higher eutrophication value than Mirabellplatz. The pollutant values gained by technical measurement by the government of Salzburg do not differ very much. At Lehen, the health threshold values for the annual mean values for nitrogen dioxide were exceeded in most years since 1998. Besides, also in Lehen, very toxitolerant lichen species like *Phaeophyscia orbicularis, Physcia adscendens* and *Physcia tenella* prevail. Nevertheless, other not so toxitolerant lichen species have been recorded in this area as well. The annual mean threshold values for particular matter have always been met at Lehen and Mirabellplatz since 1998. At Mirabellplatz, the annual mean health threshold value for nitrogen dioxide has always been exceeded. In addition, at Mirabellplatz the more toxitolerant species like *Phaeophyscia orbicularis, Physcia adscendens* and *Physcia tenella* are again the most abundant.

The reason why there is a slight difference in air quality index between Lehen and Mirabellplatz cannot be explained by the pollutant values taken by technical measurement.

Regarding the lichen species which occur in the three sites of technical measurement, only toxitolerant species are able to maintain themselves. Other species are able to survive but mostly in a lower number, and sometimes they do not occur at all.

Consequently, one pattern can be seen: higher pollutant values lead to a worse air quality index. Especially high nitrogen dioxide values seem to be the reason for low air quality. Sulphur dioxide does not play an important role concerning air quality index, maybe because of the strict laws which were passed in the past.

**Tab. 9**: Health threshold values for air pollutants (Internet 4).

| Threshold values | HMV | DMV | AMV |
|---|---|---|---|
| SO2 [µg/m³] | 200 | 120 | |
| NO2 [µg/m³] | 200 | | 30* |
| PM10 [µg/m³] | | 50 | 40 |

Abbreviations:

| | |
|---|---|
| DMV | day mean value |
| HMMV | half hour maximum mean value |
| AQI | air quality index |

*shall be met by 1.1.2012

## 3.5 Comparison with Roth 1988 and Schulmeister 1996

Roth 1988 assessed air quality using the method of Türk & Ziegelberger 1982. Schulmeister 1996 used the method of Türk & Ziegelberger 1982 as well and VDI-Guidline 3799, Herzig method Herzig et al. 1987. In the present study, VDI-Guidline 3957 Part 13 was used to assess the current air pollution and to serve as a basis for subsequent investigations. Facing the differential methods in these three studies, a comparison is only a rough estimation of tendencies.

In Roth 1988, 114 lichen species on approximately 2500 trees of various species were found. Schulmeister 1996 mapped 100 lichen species on 716 trees of 30 different species. In the present study only 55 lichen species were recorded on 440 trees of 6 species. There has been a huge decline in lichen species. One reason may be the smaller number of trees used in the present study and method. But also the tree species number is a lot smaller than in the other two studies. In this investigation, trees with similar bark properties (more or less acidic under natural conditions) were used for the recording, whereas in the former studies no distinctions were made. Therefore a wider ecological amplitude of factors influencing lichen survival

**Tab. 10**: Summary 2009 of air pollutant data and corresponding air quality index (Land Salzburg 2009).

| Summary | NO2 [µg/m³] | | SO2 [µg/m³] | | PM10 [µg/m³] | | AQI |
|---|---|---|---|---|---|---|---|
| | DMV | HMMV | DMV | HMMV | DMV | HMMV | |
| Lehen | | | | | | | |
| 2009 1. half-year | 33,7 | 64,0 | 2,9 | 6,7 | 20,1 | 199,0 | 3.E3 |
| Rudolfsplatz | | | | | | | |
| 2009 1. half-year | 67,0 | 129,7 | | | 25,5 | 165,7 | 2.E1 |
| Mirabellplatz | | | | | | | |
| 2009 1. half-year | 38,4 | 69,3 | 3,3 | 6,9 | 31,2 | 199,2 | 3.E2 |

Abbreviations:

| | |
|---|---|
| DMV | day mean value |
| HMMV | half hour maximum mean value |
| AQI | air quality index |

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**Tab. 11**: Summary 2009 of air pollutant data and corresponding air quality index (LAND SALZBURG 2009).

| Summary | NO2 [µg/m³] | | SO2 [µg/m³] | | PM10 [µg/m³] | | AQI |
|---|---|---|---|---|---|---|---|
| | DMV | HMMV | DMV | HMMV | DMV | HMMV | |
| Lehen | | | | | | | |
| 2009 1. half-year | 33,7 | 64,0 | 2,9 | 6,7 | 20,1 | 199,0 | 3.E3 |
| Rudolfsplatz | | | | | | | |
| 2009 1. half-year | 67,0 | 129,7 | | | 25,5 | 165,7 | 2.E1 |
| Mirabellplatz | | | | | | | |
| 2009 1. half-year | 38,4 | 69,3 | 3,3 | 6,9 | 31,2 | 199,2 | 3.E2 |

Abbreviations:

| | |
|---|---|
| DMV | day mean value |
| HMMV | half hour maximum mean value |
| AQI | air quality index |

**Tab. 12**: Comparison of air quality indices obtained by original calculation and recalculation and their relative frequency in the area of investigation.

| Air quality index | Number of sampling units original calculation | Number of sampling units recalculation | Percentage value original calculation in % | Percentage value recalculation in % |
|---|---|---|---|---|
| 1.E1 | | 6 | | 7,7 |
| 2.E1 | 7 | 27 | 9,0 | 34,6 |
| 2.E2 | | 2 | | 2,6 |
| 3.E1 | 28 | 7 | 35,9 | 9,0 |
| 3.E2 | 11 | 21 | 14,1 | 26,9 |
| 3.E3 | 8 | 11 | 10,3 | 14,1 |
| 3.E4 | 2 | 2 | 2,6 | 2,6 |
| 4.E1 | 10 | | 12,8 | |
| 4.E2 | 8 | 2 | 10,3 | 2,6 |
| 4.E3 | 3 | | 3,8 | |
| 5.E2 | 1 | | 1,3 | |

were recorded in SCHULMEISTER 1996 and in ROTH 1988. Hence, lichens of different ecological requirements could be reached and recorded. This was not the case in the present investigation.

With regard to the lichen species which were found, an impoverishment of lichens species from 1988 to 2009 can be seen. Whereas in ROTH 1988, species sensitive to air pollution were still found in Salzburg, in SCHULMEISTER 1996 their numbers were already declining. In 2009, genera still recorded in ROTH 1988 like Certraria sp., Evernia sp., Peltigera sp., Platismatia sp., were completely gone. Already in SCHULMEISTER 1996 genera like Peltigera sp., Bryoria sp., etc. were becoming rare. Although *Evernia prunastri* (L.) Ach. was able expand its area of occurrence from 1988 to 1996. Nonetheless, in 2009 none of these genera were recorded. Notably in ROTH 1988 and SCHULMEISTER 1996 and in the present study, rather toxitolerant species were the ones with the highest abundance. In conclusion, regarding the lichen species occurring there has been a clear deterioration of air quality in the last 20 years.

Regarding the air pollutants a shift has occurred. In 1988 sulphur dioxide was still a major problem. This pattern has shifted to a higher input of nitrogen which favours nitrophytic lichens. With this shift, acidophilic lichens were displaced by more nitrophytic lichens.

Furthermore, in ROTH 1988 the highest lichen diversity was recorded on trees with bark properties with a high pH value. This was probably due to the still high sulphur dioxide values at the time, because trees with more acidic barks may have became too acidic for lichens in the case of high sulphur dioxide pollution. In SCHULMEISTER 1996 highest air quality was found on barks with moderately acidic conditions. Lichens with different ecological requirements are able to live at such moderate conditions. In the present study, trees with more or less acidic barks under natural conditions were used. Because of high nitrogen dioxide values, lichens which are in the range of these pH value conditions or a little more on the alkaline side were most abundant. Also, lichens which had the highest toxitolerance according to ELLENBERG et al. 1992 were the most abundant.

To sum up, air quality has declined from 1988 and 1996 to 2009. This conclusion is drawn by analysing the occurrence of lichen species, as other methods may not work because of the different methods used.

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### 3.6 Critical view of the method and recalculation of air quality indices

Overall, the VDI-Guideline 3957 Part 13 is a very good tool to assess current air pollution situation, as it considers the development of the air pollutants over the last years. There has been a shift in the composition of air pollutants from acidic (favoring acidophytes) to rather alkaline fertilizing conditions favoring neutrophytes and indicators of eutrophication (Verein Deutscher Ingenieure 2005).

What is lost in the method used is the floristic aspect. The VDI-Guideline cannot be used for a complete assessment of lichen species occurring in an area. Notably, it is not the goal of the method to produce a complete list of lichen species in an area.

Besides, a tree may be free of lichens except for cracks in the bark where there are better conditions for living. A high diversity of lichens occurring in such cracks would mean high air quality is obtained in the VDI method.

A further critical aspect is the vitality of lichens. Although the vitality is noted on the record sheet, it is not considered in the calculation of the air quality index.

In addition, considering large healthy lichen thalli, the monitoring quadrates on tree trunks might become too small to include the full diversity. This was, however, no problem in Salzburg, as there were hardly any large healthy thalli.

In this investigation, two very toxitolerant lichens were very abundant (Tab. 11). *Candelariella xanthostigma* was the most abundant lichen in Salzburg and *Lepraria* sp. was the second most abundant lichen species/genus. Except for *Lepraria* sp., where there are no indicator values available, the other species does have the third highest toxitolerance within this investigation. *Candelariella xanthostigma* occurs on nutrient rich barks and *Lepraria* sp. is abundant in areas with high air pollution (Kirschbaum & Wirth, 1997). Considering the high abundance of the two lichens species and their effect on the calculation of the air quality index, the two lichens are taken out of the study and a recalculation (Tab. 12) of the air quality index is appropriate. Additionally, a new map of the air quality zones of Salzburg is drawn (Fig. 5).

Air quality zones in Salzburg after recalculation (leaving out two species) Map 2

Overall, it is plain to see that the air quality declined dramatically after leaving out *Candelariella xanthostigma* and *Lepraria* sp. (Fig. 5). This underlines the tendency of declining air quality since Roth 1988 and Schulmeister 1996 as well as the rather high pollutant values obtained by technical measurements of the government of Salzburg. Leaving out the two most abundant lichens reveals the real air quality in Salzburg, as these two species are so resistant to air pollutants that the result with them included is biased.

After recalculation, a new air quality index appears on 6 sites, namely 1.E1 which means very low air quality with very little influence of eutrophicating substances and very low diversity of the indicators for eutrophication. Mapping this air quality meant that lichen growth of any species was hardly detected; neither reference species nor indicators for eutrophication are able to grow. Furthermore, air quality index 2.E2, which means low air quality, low diversity of the indicators for eutrophication and low influence of eutrophicating substances was detected in two sampling sites after recalculation. The air qualities 4.E1, 4.E3, 5.E2 could not be found anymore in Salzburg; lower air qualities took their place. Only air quality 4.E2 was found after recalculation in two sampling sites. Altogether, high air quality and very high air quality disappeared nearly completely except for two sampling sites (compared to formally 22). Moderate air quality prevails with 52,6 % followed by low air quality with 37,2 % followed by very low air quality with 7,7 % and high air quality with 2,6 % (Tab. 12).

In conclusion, air quality declined dramatically after leaving out the two most abundant species.

## 4. Conclusion

In brief, moderate air quality prevails in Salzburg. Comparing air quality indices with technical measurement, an overall trend can be seen. High pollutant values of technical measurement correspond with low air quality obtained by lichen mapping. Comparison with Roth 1988 and Schulmeister 1996 revealed a tendency of declining air quality since the time of those studies. Additionally, recalculations of the air quality indices after leaving out the two most abundant species revealed a shocking fact. Air quality is worse than expected. Actions to save our environment and clean the air are recommended otherwise lichen species will continue completely retreating, as they already have compared to Roth 1988 and Schulmeister 1996.

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