# Monitoring climate change with lichens as bioindicators

# Suivi du changement climatique à l'aide des lichens comme bioindicateurs

N.J. Stapper[1], V. John[2]

## Abstract

Lichens are known to be very sensitive to environmental changes. Quite recently it was shown that they also respond to global warming. A mapping guideline (VDI 3957 Part 20) is under way specifying 45 «climate change indicators», all of which are epiphytic lichens that meet certain criteria related to Wirth's revised ecological indicator figures, i.e. (10-K+T)/2 > 6 with N<7 and F>6, or if no indicator figure has been published, lichens with temperate-Mediterranean and subAtlantic-Mediterranean distribution in Europe. To assess regional ecological consequences of global climate change, in Düsseldorf (Germany) and the surrounding Mettmann County, long term monitoring programs including epiphytic lichens were launched in 2008 and 2009, respectively, the results of which can be merged with those of earlier lichen studies done with the same methodology. Thus, the dynamic change of lichens on phorophytes selected according to VDI 3957 Part 13 could be analyzed over the period 2001 to 2013. Over the years, a total of 100 species were recorded. While the mean number of lichens per phorophyte increased only slightly, the mean number of climate change indicators per tree has at least doubled since 2001. The frequency of nitrophytic lichens (expressed as the proportion of the phorophytes with at least one thallus of the respective species) remains high, while acidophytic lichens are still declining. The frequency of climate change indicators, however, has been increasing steadily over the years: Punctelia subrudecta (+2,6 %/year) > P. jeckeri > P. borreri > Flavoparmelia soredians (+0,6 %/year) > Hypotrachyna afrorevoluta (+0,1 %/year) just to name a few species. Some of the indicator lichens, e.g. Parmotrema reticulatum or Physcia tribacioides, have never been recorded previously in Düsseldorf and the urban hinterland. It is suggested that these observations can, at least in part, be related to climate alterations, because in the area under investigation, mean annual temperature and the mean annual number of days with more than 25 °C are rising steadily.

## Keywords

epiphytic lichens, biomonitoring, climate change, urban climate, North-Western Germany

## Résumé

Les lichens sont connus pour être très sensibles aux variations de leur environnement. Plus récemment, il a été montré qu'ils réagissent aussi au changement climatique. Une directive (VDI 3957 Partie 20) est en cours et spécifie 45 « indicateurs de changement climatique », qui sont tous des lichens épiphytes qui correspondent à certains critères d'indicateur écologique révisé selon Witrh, soit (10-K+T)/2 > 6 avec N < 7 et F > 6, ou si aucun indicateur n'a été publié, les lichens ayant une distribution méditerranéenne tempérée et sub-atlantique-méditeranéenne sont référencés. Pour évaluer les conséquences écologiques régionales du changement climatique, à Düsseldorf (Allemagne) et aux alentours de la région de Mettmann, des programmes de surveillance à long terme, incluant les lichens épiphytes, ont été lancés en 2008 et 2009, respectivement, et dont les résultats peuvent être fusionnés avec ceux des études de lichens antérieures faites avec la même méthodologie. Ainsi, le changement dynamique des lichens sur les phorophytes sélectionnés selon VDI 3957 Partie 13 pourrait être analysé sur la période 2001-2013. Au fil des ans, un total de 100 espèces ont été enregistrées. Alors que le nombre moyen de lichens par phorophyte n'a augmenté que légèrement, le nombre moyen d'indicateurs du changement climatique par arbre a au moins doublé depuis 2001. La fréquence des lichens nitrophiles (exprimée en proportion de phorophytes avec au moins un thalle des espèces correspondantes) reste élevée, tandis que les lichens acidophiles sont toujours en déclin. Cependant, la fréquence des indicateurs du changement climatique n'a cessé d'augmenter d'année en année : Punctelia subrudecta (+2,6 %/an) > P. jeckeri > P. borreri > Flavoparmelia soredians (+0,6 %/an) > Hypotrachyna afrorevoluta (+0,1 %/an) juste pour ne nommer que quelques espèces. Certains des lichens indicateurs, par exemple Parmotrema reticulatum ou Physcia tribacioides, n'ont jamais été référencés auparavant dans Düsseldorf et sa périphérie urbaine. Il est suggéré que ces observations peuvent, au moins en partie, être liées aux modifications climatiques, puisque dans la zone étudiée, la température annuelle moyenne et le nombre de jours moyen par an avec plus de 25 °C sont en hausse constante.

## Mots-clés

lichens épiphytes, biosurveillance, changement climatique, climat urbain, Nord-Ouest de l'Allemagne.

*(1) IBüro für Ökologische Studien, Verresbergerstraße 55, 40789 Monheim am Rhein, Deutschland – nstapper@t-online.de*
*(2) Pfalzmuseum für Naturkunde, Hermann-Schäfer-Straße17, 67098 Bad Dürkheim, Deutschland*


https://doi.org/10.4267/pollution-atmospherique.4936

## 1. Introduction

Due to their physiological properties, lichens rapidly respond to physical and chemical habitat changes. Epiphytic lichens have been widely used as indicators of air pollution and to assess impacts on air quality by acidous or eutrophicating pollutants and transport related emissions (Nylander, 1866; Hawksworth et al., 1970; Van Herk 1999; Vorbeck et al. 2002; Franzen et al., 2002). Standardized mapping of epiphytic lichens enables temporal and spatial comparisons of lichen vegetation and thus, by implication, the living conditions for these organisms in a study area (VDI 3957, sheet 13). Apart from air pollutants, long-term survival of lichens is largely influenced by light, humidity and temperature. Therefore, lichens are also suitable as indicators for biological impacts of urban climate (Steiner et al., 1955; Stapper et al., 2012), climate alterations or the global change (Aptroot, 2009). Changes in the epiphytic lichen flora of the Netherlands indicate a recent and significant shift towards species preferring warm circumstances (Van Herk et al., 2002). Similar observations are reported from Germany (De Bruyn et al., 2009; Stapper et al., 2011).

In order to make use of lichens as bioindicators of climate change in a standardized procedure, a lichen mapping guideline (Draft Directive VDI 3957 Part 20, (VDI 3957, part 20)) is under way specifying 45 so called “climate change indicators”, all of which epiphytic lichens that meet certain criteria related to Wirth's revised ecological indicator figures for lichens (Wirth et al., 2010), predominantly thermophilic lichens which are more or less restricted to Western or Central Europe (10-K+T)/2 > 6; with K = continentality figure, and T = temperature figure) and adapted to humid sites (moisture value F>6). To prevent interference with eutrophication, lichens with N figures above 6 have been excluded. Also included are some lichens for which no indicator figure has been published so far with, however, temperate Mediterranean and sub-Atlantic Mediterranean distribution in Europe according to the Dutch lichen checklist (Aptroot et al., 2009; BLGW, 2011). The frequency of these indicator lichens recorded on phorophytes which are called standard trees because they have to meet strict selection criteria, is used as measured variable. The method focusses on temporal changes. Data derived from previous surveys may be employed as long as the phorophyte selection criteria have been respected e.g. they have been performed according to VDI 3799 Part 1 (VDI 3799, sheet 1) or VDI 3957 Part 13 (VDI 3957, sheet 13).

Meanwhile, preliminary versions of this guideline have been applied in several field studies in Germany (Stapper et al., 2011; Windisch et al., 2012). In Düsseldorf and the surrounding Mettmann County (North-Western Germany), mean annual temperature has risen by 1,1 K since the 1970s, and in 2008, long term monitoring programs for the assessment of regional ecological consequences of global climate change were launched including lichens as monitoring organisms. With declining sulphur dioxide concentrations, Düsseldorf's lichen flora quickly recovered. Instead of only four in the late 1970s, 73 lichen species were recorded on standard trees in the 2003 survey (Stapper et al., 2004; Stapper et al., 2004). In the following, we report on the dynamic change of epiphytic lichens in the Düsseldorf area that, since around 2000, is characterized by an invasion and steep increase of climate change indicators. We also discuss the suitability of the lichens selected as indicators for the Draft Directive.

## 2. Methods

To study temporal changes of epiphytic lichens in repeated surveys, phorophytes with subneutral bark (predominantly Acer platanoides, A. pseudoplatanus, Fraxinus excelsior, Tilia cordata, T. platyphyllos) meeting the criteria of VDI 3957 Part 13 were selected at four sampling sites in Düsseldorf (figure 1) and at several rural or suburban locations in the Mettmann County in 2008. Some trees that had already been examined in previous studies, among them the 2003 lichen survey of Düsseldorf (Stapper et al., 2004) and a comprehensive lichen survey in NRW performed 2000 to 2001 (Franzen et al., 2002) were included if they still met the selection criteria (e.g. free-standing trees with inclination less than 10 degrees from the vertical, no bark wounds).

To record lichens on the tree trunk according to the proposed guideline VDI 3957 Part 20, the use of monitoring quadrats is not mandatory. Instead, all lichen species occurring on the trunk between 50 and 200 cm height above the ground have to be noted. This procedure imports a certain loss of standardization, it is, however, beneficial with regard to the rareness of many climate change indicator lichens. An illuminated 10x magnifying hand lens was used for field work. Samples for chemical or microscopic assessment were only taken if necessary and to an extent that allows future examination of the lichens on the phorophyte. All data of the tree locations, e.g. position, altitude, land use, influence by traffic, night temperature which are suitable for subsampling and the subsequent data analysis, were registered in the database. Preferentially, paired data from subsequent examinations of identical phorophytes were analyzed with nonparametric statistical methods.

## 3. Results and Discussion

Since the mid-1990s, lichen species diversity on standard trees in Düsseldorf and the Mettmann County is in constant change. A quick reinvasion of early colonizers, among them many nitrophytes, and a rapid decline of the former dominant Lecanora conizaeoides (figure 2) was followed by a steep increase of more or less thermophilic lichens at around 2003. Most of these lichens used to be very rare or had never been recorded so far in the Rhineland (Heibel et al., 1999), among them Parmotrema reticulatum, Punctelia borreri and Schismatomma decolorans. Hyperphyscia adglutinata, rediscovered close to the Dutch border in 2003, and Candelaria concolor, which used to be very rare in the 19th century, both became very common within the last ten years (figure 2). Meanwhile, 24 climate change indicators according to the proposed guideline VDI 3957 Part 20 have been recorded, 14 of which also occur on standard trees in Düsseldorf (table 1). While most acidophytic lichens are still receding and nitrophytic ones remain essentially unaltered (data not shown), the frequency of climate change indicators is constantly rising. The three local Punctelia species show the quickest increase (figure 2 and table 1). Overall, this observation is broadly consistent with the findings of van Herk and colleagues in the Netherlands, who suggested climate change as a reason. With regard to mean temperature Düsseldorf, Duisburg and the lowlands west of the Rhine valley belong to the warmest parts of Germany, and mean annual temperature and the number of days with more than 25 °C are steadily rising (Genssler et al., 2010).

Included in table 1 are some lichens which are potentially suitable as climate change indicators due to their distribution area in Europe as given in the Dutch lichen checklist (#). Their behavior is also respected in tables 3 and 4. Some of them, the nitrophytes Hyperphyscia adglutinata, Physconia grisea and the still very rare Phaeophyscia endophoenicea have been excluded from the VDI guideline proposal in order to prevent interference with eutrophicating pollutants.

About half of the VDI-climate change indicator species recorded in Düsseldorf so far are regarded as not threatened in the red data book of lichens in North Rhine-Westphalia (NRW; (Bültmann et al., 2010)). Most probably due to the fact, however, that for most of these lichens Düsseldorf is located close to or beyond the border of their former distribution area many of them are categorized as threatened or extinct if they have, based on historical observations, been listed at all.

Observations in NRW and published data from Lower Saxony and Saarland suggest that, at present, climate change indicators are typical for lowlands in north-western Germany (Franzen et al., 2002; De Bruyn, 2009; Stapper et al., 2013). But also in Bavaria, they have become more frequent, in particular at sampling sites along the warm Main valley in North-Western Bavaria. Recalculation of the data of a comprehensive lichen survey in NRW performed 2000 to 2001 (Franzen et al., 2002; Stapper et al., 2011) show that even at this time climate change indicators, almost lichens of the genera Flavoparmelia, Parmotrema and Punctelia, were significantly more frequent in the western half of the federal state, although in the eastern half, lichen species diversity on the average was higher and air pollution impact had always been lower in the past (Stapper et al., 2011).This result is most probably based on climatic differences, as it is suggested by the recent observation in the Mettmann County, where the number of climate change indicators is significantly lower on trees at geographically higher locations in the north-eastern sampling sites (1,67 indicator species per tree; table 3) as compared to the western sites (3,05) which are located close to the Rhine valley north of Düsseldorf. As given in table 3, the VDI-climate change indicator species with the highest average altitude in the 2013 Mettmann survey was Hypotrachyna revoluta with 126 m above sea level. This does, however, not mean that e.g. Punctelia borreri (116 m) could not be recorded at higher altitudes, but, altogether, the data in table 3 indicate that the indicator lichens indeed gather in the lower altidude classes as one would expect for suitable indicators of global warming.

The four sampling sites in Düsseldorf largely differ with regard to soil sealing and urban overwarming (figure 1). Total lichen species diversity is significantly lower in the city (9,8 species per tree in 2013) than at the suburban sampling stations north and south of the town (14,4 and 14,6 species per tree, respectively). Also, the mean number of VDI-climate change indicators on the trees is higher at the suburban sites. The change of these values, however, is higher at the warmer sites (City, Harbour) as compared to the colder suburban stations (figure 1).

While nitrophytic lichens are gathering at the bottom end of table 4 among the lichens with low average numbers of accompanying species on the phorophytes (ecological factor, EF) which also seem to be better adapted to warm locations (high mRNT values; mRNT = average night time temperature at 2 m height above the ground), acidophytic lichens behave oppositely. The VDI-climate change indicators, however, span the whole spectrum of EF- and mRNT-values, suggesting that the selected species are well suitable to monitor effects based on climatic changes in an urban environment and that there is indeed no interference with eutrophication. As in the rural to suburban Mettmann County (table 3), Hypotrachyna revoluta again turns out as the indicator lichen predominantly recorded at cooler locations within the survey. The very low mRNT of the sampling station North is based on the fact that at least half of the standard trees examined there are standing in a depressed area where, according to the Düsseldorf climate analysis (City of Düsseldorf, 1995), a lake of cold air is formed at night time. Even under these conditions, climate change indicators became clearly more frequent within the past decade (p<0,05; Wilcoxon signed-rank test).

Altogether, the reported observations suggest that it is indeed possible to assess temporal climate variation with epiphytic lichens as sensitive monitoring organisms, and that proper indicator species were selected for the proposed lichen mapping guideline to monitor climate change in Germany.

## Tables and Figures

Table 1. List of lichens suitable as indicators of climate change in Germany.

(1) Species name according to Wirth (2010). (2) Climate change indicator according to VDI Draft Directive as amended on February 12, 2014 (VDI 3957 Part 20). (3) Species suitable as climate change indicator based on biome zone as detailed in Dutch checklist of lichens (Aptroot et al., 2009; BLWG, 2011); gme = temperate Mediterranean; ssg = sub Mediterranean/Atlantic-temperate; in case of empty cells another biome zone applies or the species is not listed in the Dutch checklist. (4) Red data list status in North Rhine - Westphalia (Bültmann et al., 2010); 0 Extinct, 1 Critically endangered, 2 Endangered, 3 Vulnerable, V Near threatened, R Rare, D Data deficient, * Currently not threatened (Least Concern), n.d. unlisted. (5) R indicates lichens that have, after 2000, been recorded by the authors or colleagues in Düsseldorf or the western part of North Rhine - Westphalia. (6) Change of frequency of this lichen in Düsseldorf between 2003 and 2013; frequency is given as percentage of 119 standard trees on which the species was recorded in 2003 and in annually repeated surveys from 2008 to 2013. Numbers in brackets for records on trees added to the study in 2008.

***Liste des lichens utilisables comme indicateurs du changement climatique en Allemagne.***

***(1) Le nom des espèces selon Wirth (2010). (2) Indicateur de changement climatique selon le projet de directive VDI tel que modifié le 12 février 2014 (VDI 3957, partie 20). (3) Les espèces indicatrices du changement climatique basées selon leur répartition écologique, comme détaillé dans la liste lichénique néerlandaise (Aptroot et al., 2009 ; BLWG, 2011) ; gme = méditerranéen tempéré ; ssg = subméditerranéen/ atlantique tempéré ; dans le cas où les espèces ne sont pas référencées dans la liste néerlandaise, une autre répartition écologique s'applique alors, et les cases du tableau sont laissées vides. (4) Statut de la liste rouge en Rhénanie du Nord-Westphalie (Bültmann et al., 2010) ; 0 Disparue, 1 En danger critique, 2 En danger, 3 Vulnérable, V Quasi menacé, R Rare, D Données insuffisantes, * Actuellement non menacée (préoccupation mineure), n.d. non déterminé. (5) R indique les lichens qui ont, après 2000, été répertoriés par les auteurs ou des collègues de Düsseldorf ou de la partie occidentale de la Rhénanie du Nord-Westphalie. (6) Changement de la fréquence de ce lichen à Düsseldorf entre 2003 et 2013 ; la fréquence est donnée en pourcentage sur les 119 arbres standards sur lesquels l'espèce a été recensée en 2003 et de façon régulière lors des enquêtes annuelles de 2008 à 2013. Les chiffres entre parenthèses correspondent aux recensements sur les arbres ajoutés lors de l'étude en 2008.***

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| **Species** | **Indicator species VDI-GL** | **Bio me zone NL-SL** | **Red list NRW** | **Recorded in the Rhineland** | **Change of frequency (% / year)** |
| *Punctelia subrudecta* | VDI | gme | * | R | 2,63 |
| *Hyperphyscia adglutinata* | | gme | * | R | 1,98 |
| *Physconia grisea* | | gme | * | R | 1,62 |
| *Punctelia jeckeri* | VDI | | * | R | 1,08 |
| *Punctelia borreri* | VDI | ssg | D | R | 0,88 |
| *Flavoparmelia caperata* | VDI | gme | * | R | 0,56 |
| *Flavoparmelia soredians* | VDI | ssg | 3 | R | 0,56 |
| *Parmotrema perlatum* | VDI | gme | * | R | 0,51 |
| *Bacidina neosquamulosa* | VDI | | * | R | 0,26 |
| *Lecanora barkmaniana* | | ssg | D | R | 0,21 |
| *Hypotrachyna revoluta* | VDI | gme | 3 | R | 0,11 |
| *Hypotrachyna afrorevoluta* | VDI | ssg | n.d. | R | 0,07 |

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| **Species** | **Indicator species VDI-GL** | **Bio me zone NL-SL** | **Red list NRW** | **Recorded in the Rhineland** | **Change of frequency (% / year)** |
| *Diploicia canescens* | VDI | gme | 3 | R | (0,05) |
| *Melanohalea laciniatula* | VDI | gme | 2 | R | 0,05 |
| *Pleurosticta acetabulum* | | gme | 3 | R | 0,04 |
| *Phaeophyscia endophoenicea* | | gme | 1 | R | (0,03) |
| *Parmotrema reticulatum* | VDI | ssg | D | R | 0,02 |
| *Physcia tribacioides* | VDI | gme | D | R | 0,02 |
| *Flavopunctelia flaventior* | | gme | n.d. | R | 0 / const. |
| *Melanohalea elegantula* | VDI | | * | R | 0 / const. |
| *Arthonia pruinata* | VDI | gme | 0 | | |
| *Arthonia ruana* | VDI | | 3 | R | |
| *Bactrospora dryina* | VDI | | 0 | | |
| *Collema fasciculare* | VDI | | 0 | | |
| *Coniocarpum cinnabarinum* | VDI | | 0 | | |
| *Degelia plumbea* | VDI | | n.d. | | |
| *Fellhanera bouteillei* | VDI | gme | 1 | R | |
| *Fuscidea lightfootii* | VDI | gme | 0 | | |
| *Graphis elegans* | VDI | ssg | 0 | R | |
| *Halecania viridescens* | VDI | gme | * | R | |
| *Hypotrachyna laevigata* | VDI | | n.d. | | |
| *Jamesiella anastomosans* | | ssg | * | R | |
| *Lecanographa amylacea* | VDI | | 0 | | |
| *Lecanora hybocarpa* | VDI | gme | n.d. | | |
| *Micarea adnata* | VDI | gme | D | | |
| *Micarea viridileprosa* | VDI | gme | D | R | |
| *Nephroma laevigatum* | VDI | | 0 | | |
| *Opegrapha ochrocheila* | VDI | ssg | 2 | R | |
| *Opegrapha vermicellifera* | VDI | gme | 3 | R | |
| *Parmelia submontana* | VDI | gme | 2 | | |
| *Parmelina quercina* | VDI | gme | 0 | | |
| *Parmotrema pseudoreticulatum* | VDI | ssg | D | R | |
| *Parmotrema stuppeum* | | | 1 | R | |
| *Pertusaria hymenea* | VDI | gme | 1 | | |
| *Pertusaria trachythallina* | VDI | | 0 | | |
| *Phaeographis inusta* | VDI | gme | 0 | | |
| *Physcia tribacia* | | gme | 0 | | |
| *Porina leptalea* | VDI | gme | * | R | |
| *Pyrenula nitida* | VDI | | 2 | | |
| *Pyrenula nitidella* | VDI | | 1 | | |
| *Ropalospora viridis* | VDI | | * | | |
| *Schismatomma decolorans* | VDI | ssg | n.d. | R | |
| *Scoliciosporum gallurae* | | gme | D | | |
| *Strigula affinis* | | gme | 0 | | |
| *Strigula jamesii* | | ssg | * | | |
| *Thelotrema lepadinum* | VDI | | 1 | | |
| *Usnea florida* | VDI | | 1 | | |

Table 2. Mean number of climate change indicators recorded per standard tree in lichen mapping surveys between 1996 and 2013.

Location, altitude above sea level (m) and the number of examined standard trees is given for each study. Original data and published results. (1) Data from Franzen et al. (2002). (2) Data from trees west vs. east of GK-R 2590000 in NRW. (3) Paired data from Stapper et al. (2012) and unpublished. (4) Paired data from 37 trees in the Mettmann County (ME) that have been examined repeatedly after 2001. (5) Data from trees in different sampling areas in ME. (6) Data from Stapper et al. (2013). Significances: (*), p<0,05, (**), p<0,0005, Mann-Whitney-U-Test and (#), p<0,005, Wilcoxon-Test for paired data, comparison of consecutive results obtained with identical standard trees; (n.s.), not significantly different (p>0,05).

***Nombre moyen d'indicateurs du changement climatique répertoriés par arbre standard, dans les études cartographiques lichéniques entre 1996 et 2013.***

***Le lieu, l'altitude au-dessus du niveau de la mer (m) et le nombre d'arbres standards examinés sont donnés pour chaque étude. Les données brutes et les résultats publiés (1) Données de Franzen et al. (2002). (2) Données d'arbres d'ouest vs. est selon GK-R 2590000 en Rhénanie du Nord-Westphalie. (3) Données couplées de Stapper et al. (2012) et non publiées. (4) Données couplées de 37 arbres dans la région de Mettmann (ME) qui ont été examinés à plusieurs reprises après 2001. (5) Données provenant d'arbres dans différentes zones d'échantillonnage dans ME. (6) Données de Stapper et al. (2013). Significations : (*), p <0,05, (**), p <0,0005, Mann-Whitney U-test et (#), p <0,005, test de Wilcoxon pour les données couplées, comparaison des résultats consécutifs obtenus avec des arbres standards identiques; (n.s.), non significativement différent (p> 0,05).***

| **Location Altitude, Number of trees** | **Study year** | | | | | |
|---|---|---|---|---|---|---|
| | 2001 | 2003 | 2007 | 2009 | 2011 | 2013 |
| | (Number of climate change indicators recorded per tree) | | | | | |
| **North Rhine-Westphalia (NRW)** | | | | | | |
| NRW, eastern part (1) (R<2590000), Mean alt. 197 m, 1028 trees | 0,29 | | | | | |
| NRW, western part (1) (R<2590000), Mean alt. 110 m, 787 trees | 0,53** (2) | | | | | |
| Düsseldorf (3) 35 m; 119 trees (all sampling sites) | | 1,03 | | 1,50# | 1,89# | 2,33# |
| Mettmann County (4) 40 - 300 m, 37 trees | 1,05 | | | 1,92# | | 2,16 ns |
| Mettmann, North-East (5) Mean alt. 210 m, 36 trees | | | | 1,61 | | 1,67 |
| Mettmann, North-West (5) Mean alt.112 m, 41 trees. | | | | 2,82** | | 3,05** |
| **Saarland** | | | | | | |
| Saarlouis and Dillingen (6) 180 m, 43 trees. | | | 2,03 | | | |

Table 3. Influence of altitude on the frequency of lichens and the occurrence of climate change indicator lichens on standard trees in Mettmann County.

(1) Number of records as the number of trees on which the species was recorded; only data for species observed on at least 5 trees. (2) Average altitude above sea level (m) of trees on which this lichen was recorded (sorting criterion). (3) and (4) Reaction and Nutrition figure, respectively Wirth et al. (2010). (5) and (6) climate change indicator species as given in the legend to table 1.

***Influence de l'altitude sur la fréquence des lichens et la présence de lichens indicateurs du changement climatique sur les arbres standards dans la région de Mettmann.***

***(1) Nombre d'arbres recensés sur lesquels les espèces ont été répertoriées ; seules les données concernant les espèces observées sur au moins cinq arbres sont prises en compte. (2) Altitude moyenne au-dessus du niveau de la mer (m) pour les arbres sur lesquels ce lichen a été recensé (critère de tri). (3) et (4) indices de réaction et de nutrition selon Wirth et al. (2010). (5) et (6) espèces indicatrices du changement climatique comme indiqué dans la légende du tableau 1.***

| **Species** | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | **Number Records** | **mAlt (m)** | **R** | **N** | **VDI-GL** | **Biome Zone** |
| *Caloplaca obscurella* | 7 | **185,7** | 7 | 8 | | |
| *Candelariella xanthostigma* | 14 | **179,9** | 5 | 5 | | |
| *Bacidia adastra* | 5 | **175,0** | | | | |
| *Physcia dubia* | 15 | **148,4** | 7 | 8 | | |
| *Melanelixia glabratula* | 17 | **143,6** | 3 | 4 | | |
| *Lecanora dispersa* | 16 | **136,4** | 8 | 8 | | |
| *Lepraria incana* | 58 | **133,3** | 3 | 5 | | |
| *Xanthoria parietina* | 101 | **130,8** | 7 | 8 | | |
| *Ramalina farinacea* | 38 | **128,5** | 5 | 4 | | |
| *Physconia grisea* | 19 | **128,4** | 6 | 8 | | gme |
| *Candelaria concolor* | 107 | **127,8** | 6 | 7 | | |
| | | | | | | |
| *Hypotrachyna afrorevoluta* | 26 | 126,4 | 4 | 4 | VDI | **ssg** |
| *Physcia tenella* | 127 | 124,9 | 6 | 8 | | |
| *Parmelia sulcata* | 115 | 124,6 | 5 | 7 | | |
| *Hypogymnia physodes* | 47 | 123,9 | 3 | 3 | | |
| *Phaeophyscia orbicularis* | 114 | 121,2 | 7 | 9 | | |
| *Evernia prunastri* | 84 | 120,8 | 3 | 4 | | |
| *Candelariella reflexa* | 114 | 120,8 | 5 | 7 | | |
| *Punctelia subrudecta* | 99 | 119,3 | 4 | 5 | VDI | gme |
| *Lecanora chlarotera* | 7 | 118,4 | 6 | 5 | | |
| *Lecanora hagenii* | 9 | 118,1 | 8 | 7 | | |
| *Parmotrema perlatum* | 31 | 117,6 | 5 | 4 | VDI | gme |
| | | | | | | |
| *Melanohalea exasperatula* | 43 | 115,9 | 5 | 6 | | |
| *Punctelia borreri* | 25 | 115,6 | 5 | 6 | VDI | **ssg** |
| *Xanthoria candelaria* | 53 | 115,6 | 6 | 8 | | |
| *Hypogymnia tubulosa* | 24 | 114,9 | 5 | 4 | | |
| *Punctelia jeckeri* | 98 | 112,3 | 4 | 6 | VDI | |
| *Phaeophyscia nigricans* | 11 | 112,0 | 8 | 9 | | |
| *Lecidella elaeochroma* | 5 | 110,8 | 6 | 5 | | |
| *Xanthoria polycarpa* | 22 | 110,5 | 7 | 8 | | |
| *Lecanora barkmaniana* | 17 | 108,9 | | | | |
| *Physcia adscendens* | 73 | 108,9 | 7 | 8 | | |
| *Physcia caesia* | 54 | 108,9 | 8 | 9 | | |
| | | | | | | |
| *Amandinea punctata* | 51 | 108,6 | 5 | 7 | | |
| *Cladonia spp.* | 7 | 107,1 | 3 | 3 | | |
| *Flavoparmelia caperata* | 52 | 106,1 | 5 | 4 | VDI | gme |
| *Flavoparmelia soredians* | 16 | 104,8 | 6 | 5 | VDI | **ssg** |
| *Melanelixia subaurifera* | 85 | 104,7 | 6 | 5 | | |
| *Lecanora expallens* | 34 | 100,5 | 4 | 5 | | |
| *Hyperphyscia adglutinata* | 33 | 97,3 | 7 | 7 | | gme |
| *Cladonia coniocraea* | 5 | 93,0 | 4 | 3 | | |
| *Melanohalea elegantula* | 9 | 80,0 | 4 | 5 | VDI | |
| *Strangospora pinicola* | 6 | 74,2 | 3 | 5 | | |

Table 4. Influence of urban warming on the frequency of lichens and the average number of accompanying species on standard trees in Düsseldorf 2013.

(1) Number of records as the number of trees on which the species was recorded; only data for species observed on at least 5 trees. (2) Average night time temperature at the location of the tree (Stadt Düsseldorf, 1995); data in four classes, the darker the background color, the colder. (3) and (4) Reaction and Nutrition figure, respectively Wirth et al. (2010). (5) and (6) climate change indicator species as given in the legend to table 1. (7) EF, ecological factor, average number of accompanying lichens (sorting criterium). For a correlation analysis of the data confer table 5.

***Influence du réchauffement urbain sur la fréquence des lichens et le nombre moyen d'espèces de lichens sur les arbres standards à Düsseldorf en 2013.***

***(1) Nombre d'arbres sur lesquels les espèces ont été répertoriées ; seules des données concernant les espèces observées sur au moins cinq arbres sont considérées. (2) Moyenne des températures nocturnes sur le site de l'arbre (ville de Düsseldorf, 1995) ; données selon quatre classes définies par un code couleur du plus foncé au plus clair. (3) et (4) indices de réaction et de nutrition, selon Wirth et al. (2010). (5) et (6) Espèces indicatrices du changement climatique telles qu'elles sont indiquées dans la légende du tableau 1. (7) EF, facteur écologique, nombre moyen de lichens présents (critère de tri). Pour une analyse de corrélation des données, se référer au tableau 5.***

| **Species** | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | **Numb Rec** | **mRNT (K)** | **R** | **N** | **VDI-GL** | **Biome Zone** | **EF** |
| *Parmelia saxatilis* | 5 | **-1,80** | **3** | 3 | | | 17,60 |
| *Hypotrachyna revoluta* | 7 | **-1,43** | 5 | 4 | VDI | gme | 16,29 |
| *Candelariella xanthostigma* | 6 | -0,5 | 5 | 5 | | | 16,17 |
| *Hypogymnia tubulosa* | 21 | **-1,86** | 5 | 4 | | | 15,71 |
| *Melanelixia glabratula* | 10 | **-1,30** | **3** | 4 | | | 15,20 |
| *Hypogymnia physodes* | 57 | **-1,33** | **3** | 3 | | | 15,16 |
| *Melanohalea elegantula* | 13 | -0,85 | 4 | 5 | VDI | | 15,15 |
| *Lecanora compallens* | 6 | -1 | | | | | 15,00 |
| *Lecanora hagenii* | 7 | **-1,14** | 8 | 7 | | | 14,86 |
| *Flavoparmelia soredians* | 42 | -0,6 | 6 | 5 | VDI | **ssg** | 14,76 |
| *Xanthoria candelaria* | 53 | **-1,11** | 6 | 8 | | | 14,70 |
| *Ramalina farinacea* | 36 | **-1,14** | 5 | 4 | | | 14,67 |
| *Flavoparmelia caperata* | 79 | -0,38 | 5 | 4 | VDI | gme | 14,34 |
| *Lecanora expallens* | 49 | -0,9 | 4 | 5 | | | 14,20 |
| *Lecanora barkmaniana* | 10 | **-1,40** | | | | **ssg** | 14,20 |
| *Hypotrachyna afrorevoluta* | 11 | -1 | 4 | 4 | VDI | **ssg** | 14,18 |
| *Melanohalea exasperatula* | 33 | -0,24 | 5 | 6 | | | 14,15 |
| *Physcia caesia* | 34 | 0,06 | 8 | 9 | | | 14,15 |
| *Evernia prunastri* | 87 | -0,84 | **3** | 4 | | | 14,14 |
| *Lepraria incana* | 46 | -1,04 | **3** | 5 | | | 14,11 |
| *Melanelixia subaurifera* | 106 | -0,24 | 6 | 5 | | | 13,91 |
| *Parmotrema perlatum* | 33 | -0,09 | 5 | 4 | VDI | gme | 13,73 |
| *Xanthoria polycarpa* | 36 | -0,86 | 7 | 8 | | | 13,22 |
| *Punctelia borreri* | 42 | **0,62** | 5 | 6 | VDI | **ssg** | 13,17 |
| *Punctelia jeckeri* | 133 | -0,08 | 4 | 6 | VDI | | 13,16 |
| *Amandinea punctata* | 89 | -0,28 | 5 | 7 | | | 13,15 |
| *Lecanora chlarotera* | 7 | **-1,14** | 6 | 5 | | | 13,14 |
| *Punctelia subrudecta* | 144 | -0,06 | 4 | 5 | VDI | gme | 12,72 |
| *Candelariella reflexa* | 142 | 0,01 | 5 | 7 | | | 12,66 |
| *Physconia grisea* | 59 | **0,8** | 6 | 8 | | gme | 12,63 |
| *Parmelia sulcata* | 152 | 0,1 | 5 | 7 | | | 12,61 |
| *Lecanora dispersa* | 5 | **0,4** | 8 | 8 | | | 12,60 |
| *Physcia tenella* | 158 | 0,01 | 6 | 8 | | | 12,34 |
| *Hyperphyscia adglutinata* | 60 | **0,43** | 7 | 7 | | gme | 12,27 |
| *Candelaria concolor* | 159 | 0,29 | 6 | 7 | | | 12,16 |
| *Candelariella vitellina* | 8 | **1,88** | 5 | 8 | | | 12,13 |
| *Physcia adscendens* | 154 | 0,18 | 7 | 8 | | | 11,88 |
| *Xanthoria parietina* | 154 | **0,42** | 7 | 8 | | | 11,73 |
| *Physcia dubia* | 10 | **0,9** | 7 | 8 | | | 11,60 |
| *Bacidia neosquamulosa* | 5 | **1** | 5 | 6 | VDI | | 11,40 |
| *Phaeophyscia orbicularis* | 145 | **0,91** | 7 | 9 | | | 10,66 |
| *Phaeophyscia nigricans* | 20 | **1,85** | 8 | 9 | | | 10,55 |

Table 5. Correlation analysis of the data given in table 4.
For an explanation of the abbreviations used confer legend to table 4.

***Analyse de corrélation des données indiquées dans le tableau 4.***
***Pour une explication des abréviations utilisées, se référer à la légende du tableau 4.***

| Spearman's rang correlation ($R_s$); significant values ***in bold italics*** ($p<0{,}05$) | | | | | |
|---|---|---|---|---|---|
| | **Number of records** | **mRNT (K)** | **R** | **N** | **EF** |
| Number of records | 1,00 | ***0,32*** | 0,06 | 0,25 | ***-0,40*** |
| mRNT (K) | ***0,32*** | 1,00 | ***0,48*** | ***0,72*** | ***-0,86*** |
| R | 0,06 | ***0,48*** | 1,00 | ***0,77*** | ***-0,50*** |
| N | 0,25 | ***0,72*** | ***0,77*** | 1,00 | ***-0,72*** |
| EF | ***-0,40*** | ***-0,86*** | ***-0,50*** | ***-0,72*** | 1,00 |

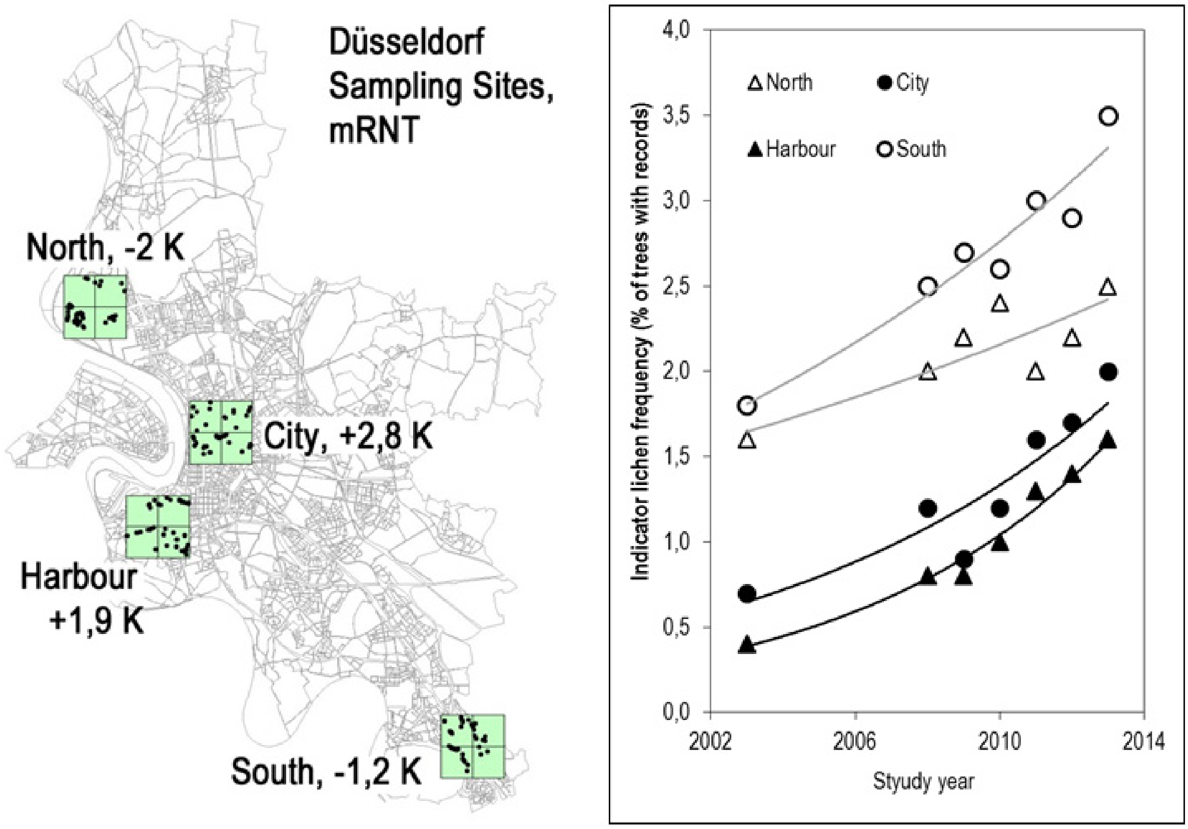


Figure 1. Development in the frequency of climate change indicator lichens on standard trees at sampling sites in Düsseldorf from 2003 to 2013.

Frequency is given as the percentage of standard trees on which climate change indicator lichen species according to the VDI guideline 3957 Part 20 were recorded during the surveys from 2003 to 2013. The location of the sampling stations is shown on the map on the left. For each station, the average night time temperature at 2 m height above the ground (mRNT in Kelvin) (City of Düsseldorf, 1995) is indicated.

***Variation de la fréquence des lichens indicateurs du changement climatique sur les arbres standards à des sites d'échantillonnage à Düsseldorf de 2003 à 2013.***

***La fréquence est donnée comme le pourcentage d'arbres standards sur lesquels les espèces de lichens indicateurs du changement climatique ont été recensés lors des études, selon la directive VDI 3957 partie 20. L'emplacement des stations d'échantillonnage est indiqué sur la carte à gauche. Pour chaque station, la température moyenne nocturne prise à 2 m de hauteur au-dessus du sol (mRNT en Kelvin) (ville de Düsseldorf, 1995) est indiquée.***

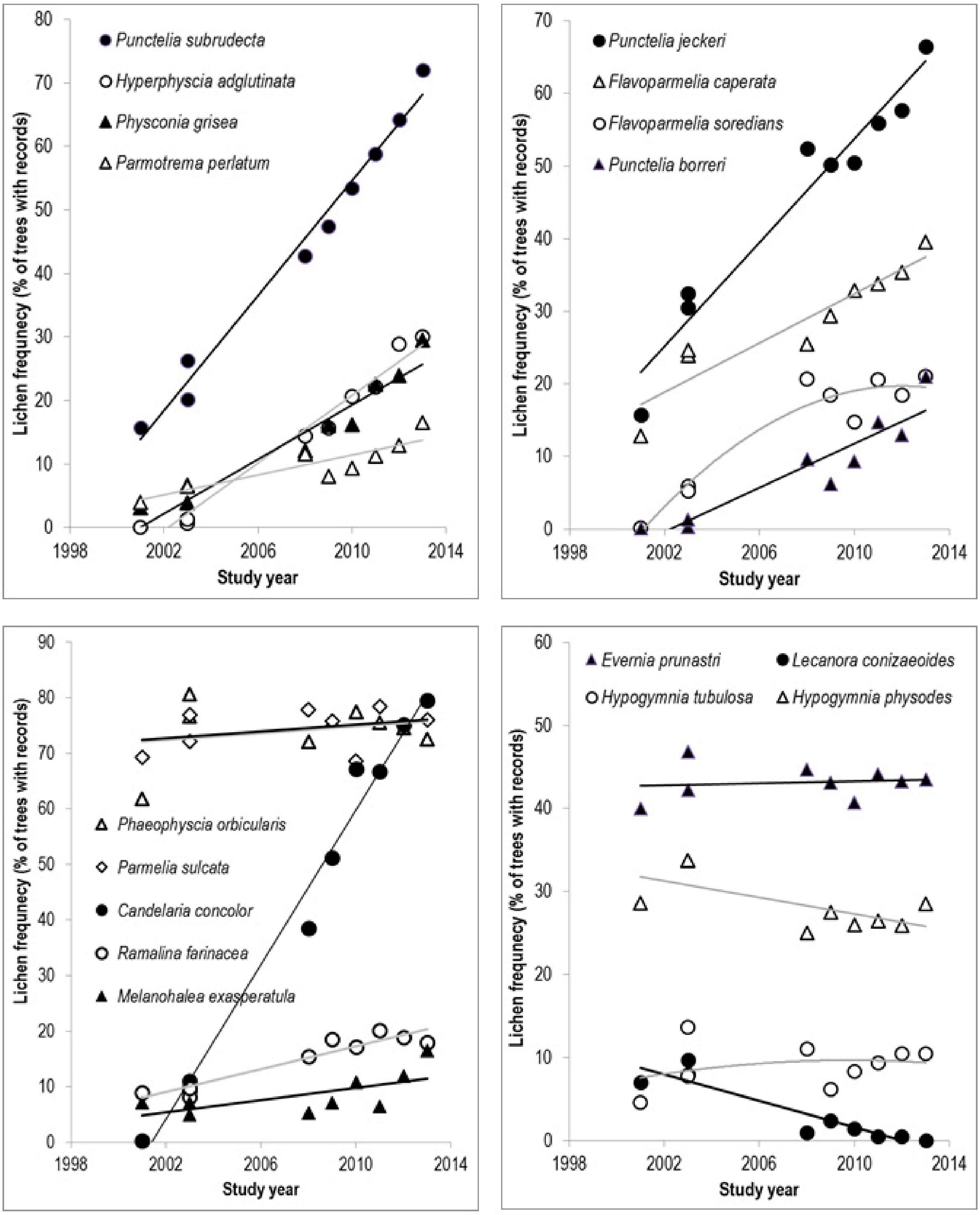


Figure 2. Change in the frequency of selected lichen species from 2001 to 2013.

Frequency is given as the percentage of standard trees on which the lichen species was recorded during the survey. 2001: data from Franzen et al. (2002) obtained on examination of 787 standard trees in western NRW with location at GK-R < 2590000. 2003 to 2013: lichen frequencies on 1015 (2003) and 211 to 200 trees (2008 to 2013) at the four sampling sites in Düsseldorf.

***Changement de la fréquence des espèces de lichens sélectionnés de 2001 à 2013.***

***La fréquence est donnée comme le pourcentage d'arbres standards sur lesquels les espèces de lichens ont été répertoriées au cours de l'étude. 2001 : données de Franzen et al. (2002) obtenues sur l'étude de 787 arbres standards dans l'ouest de la Rhénanie du Nord-Westphalie localisés au GK-R <2590000. 2003-2013 : fréquences des lichens sur 1015 arbres (en 2003) et 211 à 200 arbres (de 2008 à 2013) sur les quatre sites d'échantillonnage à Düsseldorf.***

## Références bibliographiques


Aptroot A. (2009). Lichens as an Indicator of Climate and Global Change. *Letcher TM ed. Climate Chang e: Observed impacts on Planet Earth.* Oxford, Elsevier, 444 p.

Aptroot, A. & Sparrius, L. (2009). Europese verspreiding en internationale betekenis van Nederlandse korstmossen European coverage and international significance of Dutch lichens]. *Buxbaumiella,* n° 83, p.1-12.

Bryologische en Lichenologische Werkgroep (BLWG). (2011). Standaardlijst van Nederlandse korstmossen. Verspreidingsatlas Korstmossen [Checklist of Dutch lichens. Distribution atlas of lichens]. *online. www.verspreidingsatlas.nl/korstmossen (15.01.2011).*

Bültmann H, Guderley E, Zimmermann DG. (2010). Rote Liste und Artenverzeichnis der Flechten – Lichenes – in Nordrhein-Westfalen [Red List and directory of lichen species - lichenes - in North Rhine-Westphalia]. *Landesamt für Natur, Umwelt und Verbraucherschutz NRW (Hrsg.). Recklinghausen, online : http://www.lanuv.nrw.de/natur/arten/rote_liste/pdf/RL-NW10-Flechten.pdf (18.10.2010).*

De Bruyn U, Linders HW, Mohrs K. (2009). Epiphytische Flechten im Wandel von Immissionen und Klima - Ergebnisse einer Vergleichskartierung 1989/2007 in Nordwestdeutschland [Epiphytic lichens with changing air pollution and climate - Results of a comparative mapping 1989/2007 in North western Germany]. *Umweltwiss Schadst Forsch,* n° 21, p. 63-75.

Franzen I, Stapper NJ, Frahm, JP. (2002). Ermittlung der lufthygienischen Situation Nordrhein-Westfalens mit epiphytischen Flechten und Moosen als Bioindikatoren [Determining the air quality situation of Nordrhein-Westfalen with epiphytic lichens and mosses as bioindicators]. *Gutachten im Auftrag des Ministeriums für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz Nordrhein-Westfalen, MUNLV* Düsseldorf.

Genssler L, Hädicke A, Hübner T *et al*. (2010). Klima und Klimawandel in Nordrhein-Westfalen – Daten und Hintergründe [Climate and climate change in North Rhine-Westphalia - Facts and Background]. *LANUV-Fachbericht 27.*

Hawksworth DL, Rose F. (1970). Qualitative scale for estimating sulphur dioxide air pollution in England and Wales using epiphytic lichens. *Nature* n° 227, p. 145-148.

HeibeL E. (1999). Untersuchungen zur Biodiversität der Flechten von Nordrhein-Westfalen [Studies on the biodiversity of lichens of North Rhine-Westphalia]. *Abhandlungen aus dem Westfälischen Museum für Naturkunde 61.*

Nylander W. (1866). Les lichens du Jardin du Luxembourg. *Bulletin de la Société Botanique de France* n° 13, p. 364-372.

Stadt Düsseldorf. (1995). Klimaanalyse für die Landeshauptstadt Düsseldorf. Landeshauptstadt Düsseldorf [Climate analysis for the capital of Dusseldorf], *Umweltamt.*

Stapper NJ. (2012). Baumflechten in Düsseldorf unter dem Einfluss von Luftverunreinigungen, Stadtklima und Klimawandel [Epiphytic lichens in Dusseldorf under the influence of air pollution, urban climate and climate change]. *Bibliotheca Lichenologica*, n° 108, p. 221-240.

Stapper NJ, Franzen-Reuter I, Frahm JP. (2011). Epiphytische Flechten als Wirkungsindikatoren für Klimaveränderungen im Raum Düsseldorf [Epiphytic lichens as impact indicators for climate changes in the Dusseldorf area]. *Gefahrstoffe, Reinhaltung der Luft,* n° 4, p. 173-178.

Stapper NJ, Kricke R. (2004). Luftbelastung in Düsseldorf 2003 ermittelt mit epiphytischen Flechten und Moosen als Bioindikatoren. Gutachten im Auftrag der Landeshauptstadt Düsseldorf, Der Oberbürgermeister [Air pollution determinated in 2003 at Düsseldorf with epiphytic lichens and mosses as bioindicators. Report commissioned by the City of Dusseldorf, The Lord Mayor], *Umweltamt.*

Stapper NJ, Kricke R. (2004). Epiphytische Moose und Flechten als Bioindikatoren von städtischer Überwärmung, Standorteutrophierung und verkehrsbedingten Immissionen [Epiphytic mosses and lichens as bioindicators of urban overwarming, eutrophication and transport-related imissions]. *Limprichtia,* n° 24, p.187-208.

Stapper N.J., Frahm J.-P., Franzen-Reuter I. (2013). Die Bestimmung der Stickstoff-Depositionsrate mit Hilfe von epiphytischen Flechten [The determination of the nitrogen-deposition rate with the aid of epiphytic lichens]. *Immissionsschutz*, n° 1, p. 8-15.

Steiner M, Schulze-Horn D. (1955). Über die Verbreitung und Expositionsabhängigkeit der Rindenepiphyten im Stadtgebiet von Bonn [On the dissemination and exposure dependence on the bark epiphytes in the city of Bonn]. *Decheniana,* n° 108, p. 1-16.

Van Herk CM, Aptroot A, van Dobben HF. (2002). Long-term monitoring in the Netherlands suggests that lichens respond to global warming. *Lichenologist,* n° 34, p. 141-154.

Van Herk C.M. (1999). Mapping of ammonia pollution with epiphytic lichens in The Netherlands. *Lichenologist*, n° 31, p. 9-20.

Verein Deutscher Ingenieure (VDI). VDI-Richtlinie 3957 Blatt 13. (2005). Biologische Messverfahren zur Ermittlung und Beurteilung der Wirkung von Luftverunreinigungen auf Flechten (Bioindikation). – Kartierung der Diversität epiphytischer Flechten als Indikator der Luftgüte [Biological measurement procedures for determining and evaluating the effects of ambient air pollutions by means of lichens (bioindication). Mapping the diversity of lichens as an indicator of air quality]. *Beuth,* Berlin.

Verein Deutscher Ingenieure (VDI). VDI-Richtlinie 3957 Part 20 [Draft Directive as amended on February 12, 2014]: Biologische Messverfahren zur Ermittlung und Beurteilung der Wirkung von Umweltveränderungen (Bioindikation). Kartierung von Flechten zur Ermittlung der Wirkung von lokalen Klimaveränderungen [Biological measuring techniques for the determination and evaluation of effects of environmental changes (bioindication). Mapping of lichens to determine the effects of local climate change].

Verein Deutscher Ingenieure (VDI). VDI-Richtlinie 3799, Blatt 1. (1995). Messen von Immissionswirkungen. Ermittlung und Beurteilung phytotoxischer Wirkungen von Immissionen mit Flechten. Flechtenkartierung zur Ermittlung des Luftgütewertes [Measurement of immission effects. Measurement and evaluation of phytotoxic effects of ambient air pollutants (immissions) with lichens. Mapping of lichens for assessment of air quality]. (LGW). *Beuth,* Düsseldorf.

Vorbeck A, Windisch U. (2002). Forschungs und Entwicklungsvorhaben Flechtenkartierung München – Eignung von Flechten als Bioindikatoren für verkehrsbedingte Immissionen [Research and development project lichen mapping of Munich - suitability of lichens as bioindicators for traffic-related air pollution]. *Bayerisches Staatsministerium für Landesentwicklung und Umweltfragen (StMLU).* Materialien Umwelt und Entwicklung 173. München.

Windisch U, Vorbeck A, Eichler M *et al*. (2012). Untersuchung der Wirkung des Klimawandels auf biotische Systeme in Bayern mittels Flechtenkartierung. Abschlussbericht 2011; überarbeitete Fassung vom Januar 2012 [Studying the effect of climate change on biotic systems in Bavaria by lichen mapping. Final report 2011; revised version January 2012]. *Bayerisches Landesamt für Umwelt. (Hrsg.).*

Wirth V. (2010). Ökologische Zeigerwerte von Flechten – erweiterte und aktualisierte Artenliste [Ecological indicator values of lichens – enlarged and updated species list]. *Herzogia,* n° 23, p. 229-248.

Wirth V., Hauck M, Von Brackel W *et al*. (2010). Checklist of lichens and lichenicolous fungi in Germany. Version #1: 01 December 2010. *Georg August University of Göttingen: http://www.gwdg.de/~mhauck, Göttingen,* Germany (11.12.2010).