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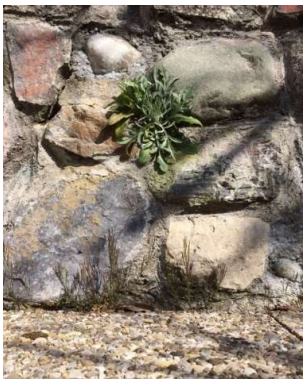
DEPARTMENT LIFE SCIENCES AND FACILITY MANAGEMENT
INSTITUTE OF NATURAL RESOURCE SCIENCES



# SPONTANEOUS URBAN VEGETATION ON ITS WAY TO GREEN WALLS

Bachelor thesis

submitted by

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Picture front page: Spontaneous vegetation on vertical wall surface and wall base joint (picture: S. Caregnato)

**Abstract**

Allowing spontaneous urban vegetation to grow on building facades directly could represent a valuable alternative to current common green walls on building, from a cost and maintenance but also biodiversity perspective.

The aim of this work is first to document characteristics of the sprouting points of plants on walls. Secondly, with the analysis of the recorded data, possible preferred structures shall be determined to be able to draw conclusions about germination and growth fostering design of construction elements for building facades.

The work covers spontaneous vegetation growing on freestanding walls, retainment walls or walls of buildings and civil constructions in Zurich, Switzerland. The wall tops, vertical wall surfaces and wall base joints are assessed separately. With statistical methods (linear models) various environmental characteristics of the walls are examined for significant influence on species richness and cover or abundance. Further, quantitative evaluation of different characteristics of the sprouting

Species cover on vertical wall surfaces is significantly positively influenced by inclination in interaction with distance from the ground of the plot and seldom maintenance. Plants use all different forms of sprouting points, i.e., joints, cracks, pores, the substantial difference in occurrence of plants in these different forms is mainly due their highly different occurrence on walls and not to a preference of the plants. Finally, water provision is the most critical point for successful facade vegetation on buildings.

To realize a good water provision on facades for plants two options could be considered in future architectural designs of facades: 1. build facade with inclination over 10°; 2. Integrate rainwater flow and water retainment in the facade elements.

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**Abbreviations**

| | |
|---|---|
| A | archaeophyte: alien plant taxon which became established in Switzerland before AD 1500 |
| AC | cultivated plant, established in Switzerland before AD 1500, able to survive in the wild without human help |
| aggr. | aggregate |
| cf. | short for the Latin "confer" meaning „compare“ |
| CR | critical endangered (according to IUCN standard risk assessment criteria) |
| EN | endangered (according to IUCN standard risk assessment criteria) |
| I | native |
| ID | identificator |
| LC | least concern (according to IUCN standard risk assessment criteria) |
| N | neophyte: alien plant taxon which became established in Switzerland after AD 1500 |
| NC | cultivated neophyte: alien plant taxon which became established in Switzerland after AD 1500, apparently unable to run wild |
| ni | European neophyte: arrived to Switzerland without human help (after AD 1500) |
| NT | near threatened (according to IUCN standard risk assessment criteria) |
| sp. | species |
| subsp. | subspecies |
| VU | vulnerable (according to IUCN standard risk assessment criteria) |
| # | number of taxa |

# 1. Introduction

Spontaneous vegetation spreads without the help of human intervention on urban open areas and constructions (public gardens, tree grates, walls, cobblestones, cracks in construction materials of buildings or civil constructions, etc.) and persists, i.e. grows and is able to reproduce despite regular human disturbance in form of maintenance work, building activity or stepping over. This vegetation is composed of native, non-native, urbanoneutral and urbanophilic species (Block, 2003; Endlicher, 2012). Abiotic factors of a site, like for example microclimate, substrate, light, water availability and the before mentioned anthropogenic factors influence which species becomes established on the place. Literature and studies (Francis & Chadwick, 2013; Francis & Hoggart, 2012; Lundholm & Marlin, 2006) indicate, that dominant species in the spontaneous urban vegetation have often origin in rocky or grassland habitats and that their over proportional presence is due to the fact that patches of the cities replicate original habitats ("Urban cliff hypothesis" (Larson et al., 2000)). Similarly, in a review paper Lundholm and Richardson (2010) come to the conclusion that nowadays urban ecosystems are not always and only considered to be new artificial ecosystems but that they are "artificial analogues" to natural systems.

According to the National Atlas Germany and studies in Germany (Block, 2003; Wania et al., 2002) spontaneous urban vegetation has a higher species richness than urban hinterland (mainly agricultural land). Not only neophytes but also native plants and archaeophytes are present in higher number in German cities (Block, 2003; Wania et al., 2002). This can be explained by cities being entrance gate for neophytes but also because of cities having more diverse structures as the hinterland (especially in the suburbs) with more different sites and environmental factors (mosaic patterns of different structure) and having also more frequent disturbance in areas / surfaces (building and civil constructions) which provide new/more habitats (Block, 2003; Endlicher, 2012; Wania et al., 2002). Similar results and explanations are stated by Landolt (2000) based on his floristic inventory of Zurich performed from 1984 to 1998. The spontaneous urban vegetation contributes to city and regional biodiversity, although often neglected or even destroyed by humans, and it can provide habitat and nourishment for different animal species (insects, lizards, birds etc.) and may also contribute to the preservation of threatened / endangered plant and animal species (Chen et al., 2020; Forman, 2014; Lundholm & Richardson, 2010; Schwartz et al., 2002).

To foster spontaneous urban vegetation and in this way perhaps further enhance biodiversity in cities, greening of seldom used surfaces - like building facades - could make a contribution (Chen et al., 2020; Forman, 2014; Lundholm & Richardson, 2010). At present the mainly used systems of planting for green walls shows however some disadvantages:

- Ground based green wall systems limit the species choice to climbing plants and few European species reach a height over 1 m.

- Wall based systems allow in principle a large plant variety as water and nutrient availability is regulated technically according to the location and the requirements of the plants. But it's quite expensive and more susceptible to technical failure.

Recent biodiversity sensitive architectural design aim to incorporate structures directly in the facade as planting / growing place for spontaneous vegetation replicating the original rocky habitat of plants, e.g. implemented project «École Primaire des Sciences et de la Biodiversité in Paris» (*Chartier Dalix*, 2021). This concept has the potential to have less disadvantages than the current main wall greening systems mentioned before.

Current spontaneous vegetation on walls in urban areas is composed in general in minor part of lichens (is limited by pollution and dry urban air), in an already greater part of mosses and mainly of vascular plants, i.e. flowering plants and ferns, rooting in cracks and joints. On the wall surface succession starts mainly with accumulation of air dust containing soil particles and with water. The first pioneer mosses and herbaceous species further retain water, dust and rotting material building up more soil and improve this way germination and growing conditions also for other species. In the original rocky habitats of those specie the natural degradation of rock and the roots of woody species would enlarge the cracks and thus produce more suitable place on the rocky surface for additional vegetation evolving in shrub or tree. But this process is in general interrupted in cities by regular and repeated restoration and maintenance work, so that the succession process starts again from the beginning (Forman, 2014).

Different studies in the last decades on spontaneous wall vegetation in England, Germany, Canada, Switzerland, New Zealand and China look at urban species richness / distribution and plant communities (Brandes, 1987; Chen et al., 2020; de Neef et al., 2008; Guggenheim, 1992; Lundholm & Marlin, 2006; Payne, 1978).. Amongst other, there aim is to contribute on the knowledge about urban spontaneous vegetation as potential contributor to urban biodiversity. The work on the urban wall vegetation of Guggenheim in Zurich (1992), of de Neef in Christchurch and Dunedin in New Zealand (2008) and of Chen in Chongqing, China (2020), in addition contain data about abiotic factors (e.g., type of wall, building material, wall inclination, aspect, percentage of cracks, sun exposure) which may influence the spontaneous urban wall vegetation. This information may be helpful for authorities, management and conservation bodies and other interested parties for conservation and promotion of spontaneous wall vegetation in urban settlements. Still these sources focus mainly on freestanding / retention walls and less on building walls. To support a fast and rich natural facade colonization by spontaneous urban vegetation additional information and knowledge about construction structures and materials of the base / substratum for the different plants / plant families currently growing on urban walls is required. The work of Lagurgue et al. (2019) analyses more in detail this aspect in urban vegetation looking specifically at the sprouting point of single plants on buildings in four streets of Paris, France. The main results of this study are: a) only in few occurrences plants had negative impact on buildings, more often they showed

no impact at all or may even have protective function; b) the presence of joints on walls is a more important factor for spontaneous vegetation than material or texture of the surface and presence of cracks; c) a proposal for seven additional characteristics of sprouting points to be used in future urban spontaneous vegetation analysis delivering information useful to constructors / scientist on the species / plant requirements related to facades incorporating germinations structures for plants. With such information, minimum requirements for base and substratum could be defined for testing purposes. In addition comparison of these minimum requirements with natural habitats of native, endangered or threatened species could be initiated to optimize the requirements with focus on those species, i.e. creating analogues habitats as suggested by Lundholm and Richardson (2010).

The aim of this work is first to document the sprouting points of plants on walls according to the extended characteristic criteria for the sprouting point of plants on buildings as suggested in the paper of Lagurgue et al. (2019, Tabelle 4.). Secondly, with the analysis of the recorded data, possible preferred structures shall be determined to be able to draw conclusions about germination and growth fostering design of construction elements for building facades.

# 2. Materials and methods

## 2.1. Study site

The wall relevés were carried out in the city of Zurich. From a geological point of view the city is situated in a region shaped during the last ice age by the Linth glacier with moraines and basins. The settlement was established at the outflow of the lake of Zurich (Figure 1). Because of various municipality incorporations in nineteenth and twentieth century (*Zürich wird zur Grossstadt - Stadt Zürich*, 2021) the municipality of Zurich is extended nowadays northwest along the Limmattal (alluvial soil) and is delimited south by the Üetliberg (870 MASL) which is part of the Albis hill chain (moraine). The areas north and northeast of city are situated in the Glatttal, which till the nineteenth century was mainly a marsh region. The Glatttal is separated from the Limmattal by the hill chains of Hönggerberg (541 m a.s.l.), Chäferberg (562 m a.s.l.), Zürichberg (675 m a.s.l.) and Adlisberg (701 m a.s.l.). The different hill chains are mainly covered with forest. The municipality including waterbody covers 92 km$^2$, the level of the lake of Zurich is at 406 m a.s.l.. The population is about 434'000 status 2019 (*Amtliche Vermessung*, 2001; *Zürich in Zahlen - Stadt Zürich*, 2021).

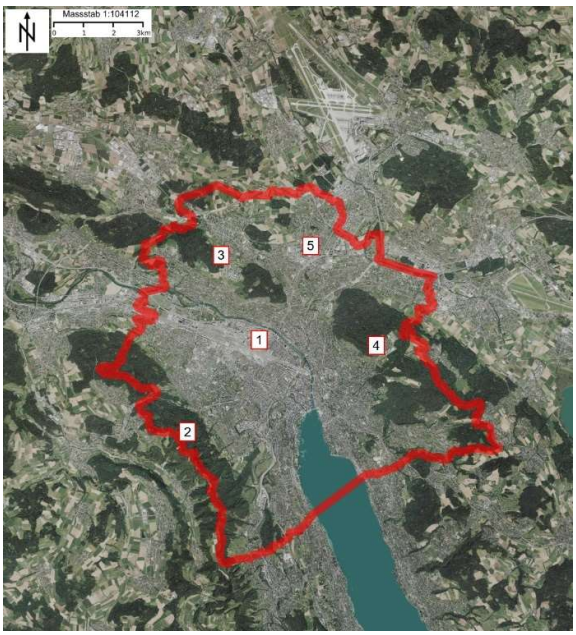



*Figure 1 Marked in red the municipality of the city of Zürich, 1 = Limmattal, 2 = Üetliberg, 3 = Hönggerberg and Chäferberg, 4 = Zürichberg and Adlisberg, 5 = Glatttal; Source: GIS ZH, canton Zürich, modified.*

The climate normal values for the period 1981-2010 list a mean annual temperature of 9.4 °C, yearly precipitation amount of 1054 mm and 1531 h sunshine duration. The average number of ice days (days with maximum temperature < 0 °C) is 20.9. Temperature and rainfall distribution per month is displayed in Figure 2 (*Klimanormwerte Meteo Station Zürich Affoltern*, 2021). In the period 2011-2020 the mean annual temperature was 10.4 °C (1 °C higher as for the period 1981-2010), the amount of precipitation was 956.1 mm per annum (approximately 100 mm less per annum as the period before) and the sunshine duration was 1781 h per annum (250 h more as in the former 10 years period) (*Messwerte Meteo Station Zürich*

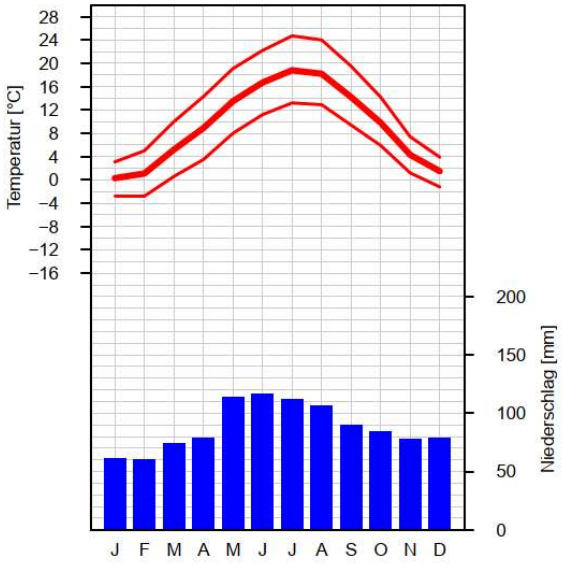


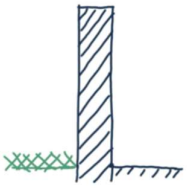
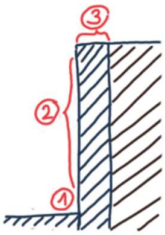
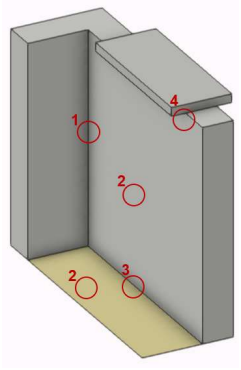
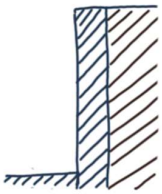
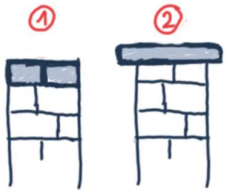
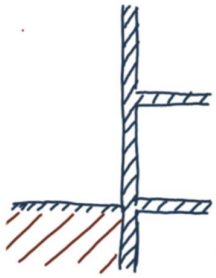
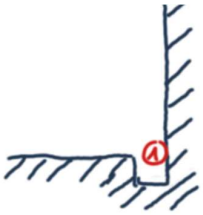

*Figure 2 Climate normal values 1981-2010: mean of all temperature measurements of one month, mean monthly daily maximum respectively minimum temperature and monthly precipitation; Source: Meteo Station Zürich-Affoltern, MeteoSchweiz.*

*Affoltern*, 2021; *Messwerte Meteo Station Zürich Fluntern*, 2021). Winds from west southwest and northeast are predominant and west southwest winds are strongest (*Windrose Meteo Station Zürich Affoltern*, 2021; *Windrose Meteo Station Zürich Fluntern*, 2021).

## 2.2. Terms

For this work terms as described in Table 1 are used.

*Table 1 Type of walls and wall elements with sectional view and forms of sprouting points (drawings S. Caregnato)*

| Wall type | Wall element | Angle of the wall surface | Form of sprouting point |
|---|---|---|---|
| **freestanding wall**  | **elements:**<br>① wall base joint<br>② vertical wall surface<br>③ wall top  | dihedral angle = angle between two surfaces<br>① vertical dihedral angle<br>② plane<br>③ horizontal dihedral angle bottom<br>④ horizontal dihedral angle top  | **joint**  |
| **retaining wall**  | **shape of the wall top:**<br>① capstone (flush fitting the vertical wall surface)<br>② cover plate (overlaps the vertical wall surface)  | | **crack**  |
| **wall of building / civil construction (e.g. bridges, viaduct)**  | ① **wall base joint**: joint formed by the vertical wall surface and the sealed / macadamized ground  | | **pore**  |

## 2.3. Sampling

In ArcGIS Pro Version 2.6.2 a graticule with mesh size 250 m was laid over the municipal area of Zurich and randomly 50 starting points for the sampling were generated in the settlement area (Figure 3). The settlement area comprehends industrial, manufacturing, building and traffic areas, special settlement areas (e.g., construction sites, waste disposal sites) as well as recreational areas and public parks as defined in Arealstatistik Nomenklatur (Bundesamt für Statistik (BFS), 2018). From this starting point the nearest walls was searched. Basis for the search were:

1. sites of stone walls respectively inclined or vertical retainment walls of rivers / lakes from habitat mapping (*Biotoptypenkartierung 1987 - Stadt Zürich*, 1987; *Biotoptypenkartierung 2020 - Stadt Zürich*, 2020)
2. sites of bridges, retainment walls and embankments from the civil construction inventory (*Kunstbauteninventar - Stadt Zürich*, 2015)
3. site of walls documented in following studies:
    - «Mauervegetation in der Stadt Zürich» (Guggenheim, 1992)
    - «Mauerbiotope in der Stadt Zürich» (Guggenheim & Ineichen, 1995)
    - «Mauer-Inventar: Revision 2015» (Hose & Ineichen, 2015)
4. randomly found walls, e.g., front yard retaining walls, wall of buildings

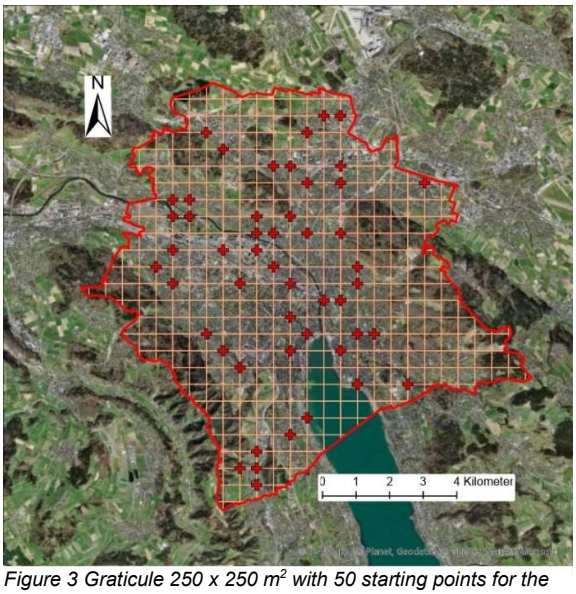



*Figure 3 Graticule 250 x 250 m² with 50 starting points for the sampling + in the settlement area of the city of Zurich; Source: swisstopo, modified.*

To avoid overlapping of search areas always the square bottom left of the starting point was scanned.

The prerequisites for a wall to be considered for a relevé have been defined as follows:

1. presence of at least two species of vascular plants on minimum one of the three wall elements (refer to Table 1 )
2. if the wall element is a vertical wall surface the surface has to have a minimum size of 4 m² (cf. chapter 2.4)
3. the wall is situated on public or semi-public area and the vegetation is accessible for identification

## 2.4. Relevé plots and transects

Segal (1969) recommends in his paper «Ecological notes on wall vegetation» a minimum plot size of 4 $m^2$ for vertical wall surfaces. For the different wall elements the following plot sizes respectively transect lengths have been set:

- Wall top: The relevé is done along a transect following the wall top length; the transect sections are each 1 m long and the vegetation up to 0.1 m right and left of the transect line were assessed. Minimum transect length: 1 m; maximum transect length: 8 m.
- Vertical wall surface: Rectangular area of 4 $m^2$
- Wall base joint: The relevé is done along a transect following the wall base joint; Transect section is 1 m long, all vegetation in the wall base joint has been assessed. Minimum transect length: 1 m; maximum transect length: 8 m.

On large walls the area with the highest species richness was selected for the relevé. Species growing on the wall but not in the plot area have been documented with "presence".

## 2.5. Data collection in the field

The relevés were carried out from June to August 2021. Both vascular plants and mosses were recorded, although mosses were not identified at species level. For each sampling, data were recorded on three levels (Figure 4) but not all samplings included data for all three type of wall elements (some walls did not have wall tops or wall base joints or some wall elements did not have a minimum two vascular plants growing). The data recorded in the level is listed in table Table 2.

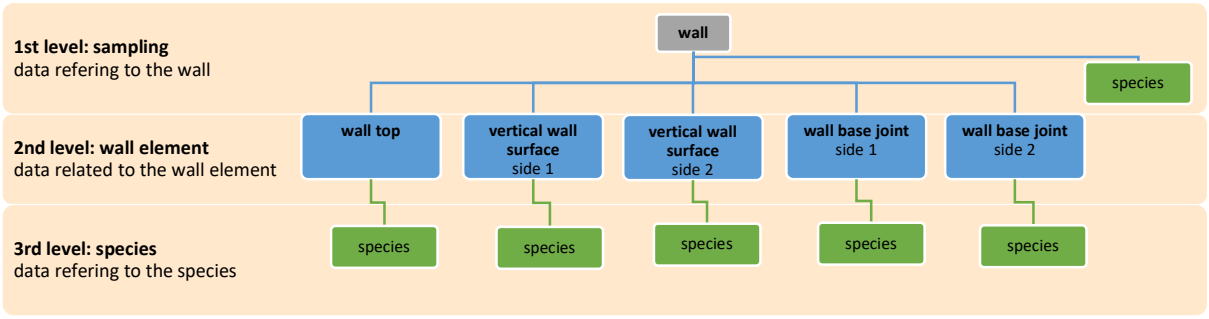



*Figure 4 Levels of data recording for each sampling.*

*Table 2 Data registered on the three levels*

| Level | Values / remarks |
|---|---|
| **1st level: sampling** | |
| • wall ID | |
| • date | |
| • coordinates | |
| • location | street name / building name / location description |
| • height [m a.s.l] | |
| • type of wall | freestanding wall / retaining wall / wall of building or civil engineering constructions |

| Level | Values / remarks |
|---|---|
| • with wall top [m] | |
| • maximal wall height [m] | |
| • length wall base [m] | |
| • aspect of the vertical wall surface | north / northeast / east / southeast / south / southwest / west / northwest |
| • other species | name of other species present on the wall not registered in the plot area |
| **2nd level: wall element** | |
| **Element: wall top** | |
| • minimum two vascular species present | yes / blank (if yes, relevé done and following information on wall element and species level registered) |
| • plot ID | |
| • shape of wall top | top / cover plate |
| • inclination [°] | measured as displayed in Figure 5 |
| • slope [°] | measured as displayed in Figure 6 |
| • material | aluminium / asphalt / brick / concrete / joint sealant / granite / cast iron / wood / limestone / ceramic / marble / mortar / plastic / sandstone / steel / zinc / copper / grass paving block / earth / macadam / natural stone |
| • maintenance | regular, i.e. minimum once a year / seldom |
| **Element: vertical wall surface [1)]** | |
| • minimum two vascular species present | yes / blank ((if yes, relevé done and following information on wall element and species level registered) |
| • plot ID | |
| • with and height [m] x [m] of the rectangular plot | |
| • height of the plot [m] | distance from wall bottom to lower border of the rectangular plot |
| • inclination [°] | measured as displayed in Figure 5 |
| • material | aluminium / asphalt / brick / concrete / joint sealant / granite / cast iron / wood / limestone / ceramic / marble / mortar / plastic / sandstone / steel / zinc / copper / grass paving block / earth / macadam / natural stone |
| • maintenance | regular, i.e. minimum once a year / seldom |
| **Element: wall base joint [1)]** | |
| • minimum two vascular species present | yes / blank (if yes, relevé done and following information on wall element and species level registered) |
| • plot ID | |
| • slope wall base joint [°] | measured as displayed in Figure 6 |
| • inclination of the ground [°] | measured as displayed in Figure 5 |
| • material | aluminium / asphalt / brick / concrete / joint sealant / granite / cast iron / wood / limestone / ceramic / marble / mortar / plastic / sandstone / steel / zinc / copper / grass paving block / earth / macadam / natural stone |
| • with wall base joint [m] | < 0.005 / ≥ 0.005 |
| • maintenance | regular, i.e. minimum once a year / seldom |
| **3rd level: species** | |
| • aspect side 2 | in case of freestanding walls with relevés on both sides of the wall (vertical wall surface and / or wall base joint) the aspect of side 2 of the wall is registered, otherwise, the aspect is same as defined on level sampling |
| • transect section number | only for wall tops and wall base joints; from 1 to maximum 8 |
| • species name | |
| • abundance | only in case of relevé on wall top or wall base joint (mosses, *Carex divulsa, Sedum rupestre* aggr*., S. spurium, Ranunculus repens* have been counted with abundance 1 as individual plant could not been determined) |
| • cover [%] | only in case of vertical wall surface relevés (cover as projection of the vegetation on the vertical wall surface) |
| characteristics of the sprouting point: | |
| • surface position | horizontal / vertical / inclined (inclined if supporting surface differs ≥ 10° from the horizontal or vertical i.e. inclination or slope measured on level wall element ≥ 10°) |

| Level | Values / remarks |
|---|---|
| • angle of the surface | plane / horizontal dihedral angle top / horizontal dihedral angle bottom / vertical dihedral angle (see *Table 1*) |
| • texture | strong roughness (like conglomerate = sedimentary rock) / week roughness (like sandstone) / smooth (like sheet metal) |
| • form of sprouting point | pore / joint / crack (see *Table 1*) |
| • substratum | masonry / loose filling material (gravel stone mixed with humus accumulated in joints of a dry stone wall) / earth |
| • sun exposure | sun (> 6 h sun per day) / partial shade (2 - 6 h sun per day) / shade (0 - 2 h sun per day) |
| • water exposure | covered / exposed to rain / exposed to trickling water / still water (after rainfall) (estimation based on distance of sprouting point to cover plate, presence of dense wall covering vegetation, different coloration of wall material due to water etc., in some cases evidence after rainfall events) |

[1)] In case of freestanding wall relevés, with more than 2 vascular species on both sides of the vertical wall surface respectively wall base joint, these information were collected for both sides of the wall.

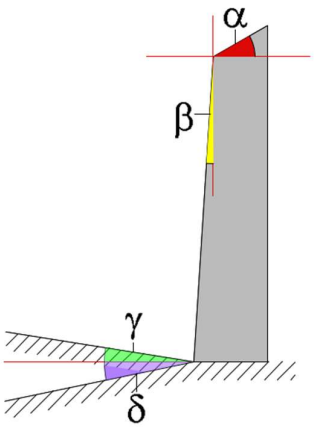



*Figure 5 Sectional view of wall with inclination angle: $\alpha$ inclination wall top; $\beta$ inclination vertical wall surface; $\gamma$ inclination ground > 0°, $\delta$ inclination ground < 0° (drawing: S. Caregnato).*

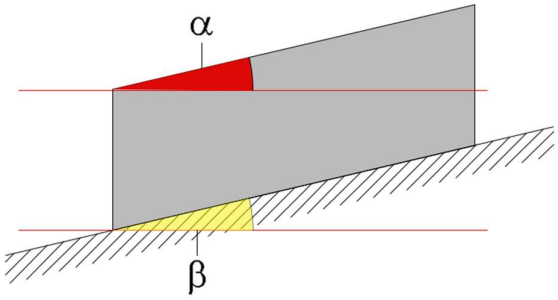



*Figure 6 Sectional view of wall with slope: $\alpha$ slope wall top; $\beta$ slope wall base joint (drawing: S. Caregnato).*

## 2.6. Materials

*Table 3 Materials used for data recording.*

| Data and data recording | Measuring device / application / source | error |
|---|---|---|
| coordinates LV95 [m] | ArcGIS Collector 20.2.4 | + / - 4 m |
| height [m a.s.l.] | https://maps.zh.ch | |
| size of wall, wall base joint [m] | folding rule; | + / - 0.01 m |
| | height of buildings / civil constructions: Google Earth | + / - 1.00 m |
| wall aspect | https://maps.zh.ch | |
| inclination / slope [°] | iPhone 5S with iOS 12.5.4: app "compass", function "water level" | estimated 0,5 mm per meter (PCShow, 2021) |
| construction material | visually | |
| identification of species | references:<br>• Flora Vegetativa: ein Bestimmungsbuch für Pflanzen der Schweiz im blütenlosen Zustand (Eggenberg et al., 2020)<br>• Flora Helvetica (Lauber et al., 2018) | |

| Data and data recording | Measuring device / application / source | error |
|---|---|---|
| | • Schul- und Exkursionsflora für die Schweiz: mit Berücksichtigung der Grenzgebiete: Bestimmungsbuch für die wildwachsenden Gefässpflanzen (Binz & Heitz, 1990) | |
| | internet sites: | |
| | • weBot (2021) | |
| | • Bochumer botanischer Verein (2021) | |
| | • info flora (2021) | |
| | • Baukunde.de (2021) | |
| | • Krautfinder (2020) | |
| | applications: | |
| | • FLORA INCOGNITA, version 2.9.9 | |
| | • PlantNet, version 3.7.4 | |
| | • iNaturalist, version 3.2.2, 646 | |
| abundance of plants | count | |
| cover [%] | estimation | |
| data collection and initial data processing | ArcGIS Collector 20.2.4, ArcGIS Pro 2.6.2 (desktop application) | |

Vascular plants have been identified using the nomenclature of "Flora Helvetica Checklist 2017 der Gefässpflanzen der Schweiz" (Juillerat et al., 2017).

For data recording a project has been created in the desktop application of the geographical information system ArcGIS Pro 2.6.2. The project has been published in ArcGIS Online where a map has been assigned for the offline data collection with app ArcGIS Collector 20.2.4 on an iPad Air (with iOS 12.5.4). The data and pictures collected via iPad were synchronized with the project in ArcGIS Online. In ArcGIS online data quality reviews and data correction were done before the project was downloaded in ArcGIS Pro for further data processing.

## 2.7. Data analysis

### 2.7.1. Data preparation for the analysis

In ArcGIS Pro all records have been amended with following information: family, native / neophyte

### 2.7.2. Analysis

Analysis of the sprouting point characteristics and the species has been conducted in Microsoft Excel for Microsoft 354 MSO, Version 2102 using the Pivot function.

For time reasons the impact of environmental factors (height and length of the wall, inclination and height of the relevé, type of wall, aspect, maintenance and material) on species richness and cover has been only analysed for vertical wall surfaces. It has been performed with the software R (R Core Team, 2020) in combination with RStudio (RStudio Team, 2020). The significance level $\alpha$ was set to 0.05. To test for potential correlations between the metric predictors/variables (height

and length of the wall, inclination and height of the relevé) the Pearson correlation coefficient R was calculated and the threshold for correlation was set to $|R| > 0.7$. Separately tested with linear regression were metric predictors for significance of the quadratic term. Significant quadratic terms were considered together with the linear terms in the full regression model. By removing the less significant term/predictor the model was simplified. Interactions between the predictors were tested using ANCOVA on maximum three predictors at the time and permuting the predictors. Significant interactions were added to the simplified model and the resulting adjusted $R^2$ value of the models compared to each other. The final model (i.e., best model) is the model with the highest adjusted $R^2$ value.

The Excel file is available in Appendix 8, R script in Appendix 9 and data for R script in Appendix 10.

# 3. Results

## 3.1. Overview of the sampling and the classified species and families

Starting from the 50 random crosses a wall fulfilling the sampling requirements has been found in most cases in the square on the right below the cross (Figure 7), the search in the square stopped and the relevé started. Only in two cases the search area had to be extended to a square further below (wall ID 37) respectively for the southernmost cross, as not even in the adjacent squares an appropriate wall could be found, a previously additionally recorded wall plot in square has been used (wall ID 8).

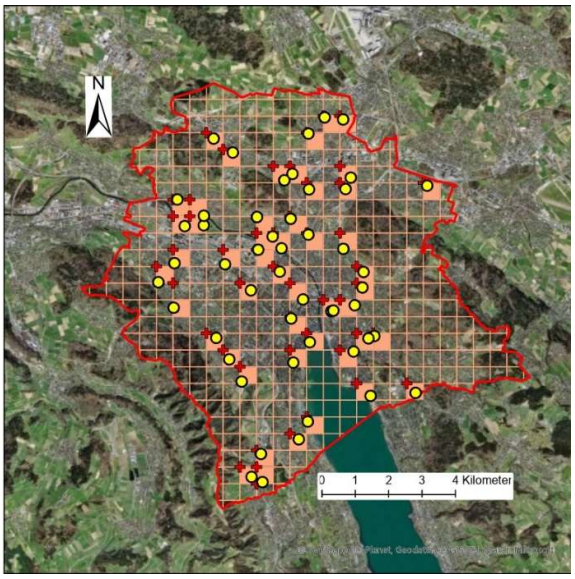



*Figure 7 Graticule 250 x 250 m² with 50 random starting crosses + for the sampling in the settlement area in Zurich. The dot ○ marks the location of the walls found in the square ▱; Source: swisstopo, modified.*

Out of these 50 walls (Appendix 2 Listing of wall locations) 7 were freestanding walls, 39 retaining walls and 4 walls of buildings or civil engineering structures. Only one of the freestanding walls fulfilled the requirements for relevé on both sides of the wall and this only on the wall base joint. In total 75 relevés were done: 11 relevés on the wall top, 33 on the vertical wall surface and 31 on the wall base joint (Table 4).

*Table 4 Overview of the number of walls with relevés on one, two or all three wall elements as well as the main construction material oft he walls.*

| Relevés | | | # walls | Material | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| top | vertical surface | base joint | | brick | concrete | granite | limestone | natural stone | sand-stone | other[3)] |
| X[1)] | X | X | 7 | | | 2 | 2 | | 4 | |
| X | X | | 1 | | | | | | 1 | |
| X[1)] | | X | 2 | | 1 | 1 | | 1 | | |
| X | | | 1 | | 1 | | | | | |
| | X | X | 7 | | 1 | 3 | | | 3 | |
| | X | | 18 | 1 | 1 | 2 | 2 | 3 | 9 | |
| | | X[2)] | 14 | | 10 | | | | 2 | 3 |
| 11 | 33 | 31 | | 1 | 14 | 8 | 4 | 4 | 19 | 3 |
| | **75** | | **50** | | | | | | | |

[1)] One wall top consists of different material as the vertical wall surface / wall base joint
[2)] One freestanding wall has two relevés on the wall base joint as
[3)] On building with sheet metal at the wall base joint, two walls concrete - gravel conglomerate

The 75 relevés include 970 records (Appendix 1 Raw data). 84 records are related to transect sections of wall top or wall base joint with zero vegetation. 85 records are mosses, which were not further classified at species level. Neither species nor genus could be determined for 4 records (2 species) whereas for the remaining 797 records plants from 46 different families were identified. The genus / species could be determined with uncertainty (marked with "cf.") for 32 records, 73 plants have been determined only at genus level (3 only uncertain) whereas the remaining 694

vascular plants have been identified at species level with certitude. Overall, 173 species were found (Appendix 3 Genera and species), 15 have been determined with uncertainty and 158 with certitude; 44 species have been recorded only as present with no further details about the germination environment. Poaceae is the most species-rich family (26 taxa), followed by Asteraceae (21) and Plantaginaceae (14) (Table 5).

*Table 5 Number of genera / species (determined with certainty or uncertainty) per family.*

| family | # genera / species | family | # genera / species | family | # genera / species |
|---|---|---|---|---|---|
| Poaceae | 26 | Violaceae | 3 | Taxaceae | 1 |
| Asteraceae | 21 | Cyperaceae | 3 | Paulowniaceae | 1 |
| Plantaginaceae | 14 | Malvaceae | 2 | Adoxaceae | 1 |
| Lamiaceae | 13 | Sapindaceae | 2 | Pinaceae | 1 |
| Caryophyllaceae | 8 | Geraniaceae | 2 | Convolvulaceae | 1 |
| Rosaceae | 6 | Oxalidaceae | 2 | Dryopteridaceae | 1 |
| Brassicaceae | 6 | Boraginaceae | 2 | Saxifragaceae | 1 |
| Fabaceae | 6 | Primulaceae | 2 | Campanulaceae | 1 |
| Ranunculaceae | 5 | Euphorbiaceae | 2 | Simaroubaceae | 1 |
| Betulaceae | 5 | Hydrangeaceae | 2 | Caprifoliaceae | 1 |
| Aspleniaceae | 4 | Scrophulariaceae | 1 | Urticaceae | 1 |
| Onagraceae | 4 | Rubiaceae | 1 | Fagaceae | 1 |
| Polygonaceae | 3 | Oleaceae | 1 | Apiaceae | 1 |
| Salicaceae | 3 | Cupressaceae | 1 | Asparagaceae | 1 |
| Crassulaceae | 3 | Cornaceae | 1 | **total** | **172** |
| Papaveraceae | 3 | Araliaceae | 1 | | |

Comparing the species found with the national red list (Bundesamt für Umwelt, 2016) resulted in one species as vulnerable (*Teucrium botrys*) and two are near threatened (Table 6).

*Table 6 Level of endangerment oft he assessed plants according to the national red list of the endangered vascular plants (Bundesamt für Umwelt, 2016).*

| Species | native | wall ID | status |
|---|---|---|---|
| *Teucrium botrys* | I | 14, 18 | VU |
| *Diplotaxis muralis* | A | 32 | NT |
| *Silene coronaria* | I | 29 | NT |
| other species from Appendix 3 | | | LC |

Furthermore 41 species found were neophytes, occurring on 32 of the total 50 walls. Three of them are invasive and another three are on the watch list (info flora, 2014) As displayed in Table 7 all six were present on vertical wall surfaces, all invasive neophytes were present also on wall base joints and *Sedum spurium* from the watch list was found on all three wall elements.

*Table 7 Invasive neophytes (BL blacklist) and neophytes on the watch list (WL) with their presence on the walls / wall elements.*

| species | list | # walls | wall top | vertical wall surface | wall base joint |
|---|---|---|---|---|---|
| *Ailanthus altissima* | BL | 2 | | X | X |
| *Buddleja davidii* | BL | 2 | | X | X |
| *Erigeron annuus* | BL | 5 | | X | X |
| *Cornus sericea* | WL | 1 | | X | |
| *Paulownia tomentosa* | WL | 1 | | X | |
| *Sedum spurium* | WL | 3 | X | X | X |

On wall top 2 neophyte species occurred, on vertical wall surfaces 22 and on wall base joint 28. Wall base joint showed not only the highest number of neophyte specie but also the highest

percentage (22.2 %) when compared to total species. Although, considering only the plot areas and not the whole wall, the percentage was lower for wall base joints (18.5 %) than for vertical walls (21.1 %). Furthermore, in the plots the abundance of neophytes in relation to total abundance was 3.1 % for wall top and 9.2 % for wall base joint. For vertical wall surfaces the cover (in percent of the total vertical wall plot area) was 1.1 % for neophytes and 14.2 % for all species, i.e., 7.8 % of vegetation cover was attributable to neophytes (Table 8). Wall top and vertical wall surface together had 20.4 % neophytes.

*Table 8 Neophytes on the three different wall elements: number of species, abundance (for wall tops and wall base joints) and cover (for vertical wall surfaces, in % of total plot area)*

| | wall top | vertical wall surface | wall base joint | wall top and vertical wall surface |
|---|---|---|---|---|
| **# neophyte species on wall** | 2 | 22 | 28 | 23 |
| **total species on wall** | 41 | 106 | 126 | 113 |
| **% of neophyte species on wall** | 4.9 | 20.8 | 22.2 | 20.4 |
| | | | | |
| **# neophyte species in plots** | 1 | 16 | 23 | 16 |
| **total species in plots** | 28 | 76 | 124 | 78 |
| **% of neophyte species in plots** | 3.6 | 21.1 | 18.5 | 20.5 |
| | | | | |
| **abundance neophyte** | 4 | | 96 | |
| **abundance all species** | 129 | | 1040 | |
| **% of neophyte abundance in plots** | 3.1 | | 9.2 | |
| | | | | |
| **cover [%] neophyte** | | 1.1 | | |
| **cover [%] all species** | | 14.2 | | |

The sprouting points of the neophytes in the plot areas showed following characteristics: mainly they sprouted in joints; on wall top they occurred under partial shade, on vertical wall surfaces mainly under partial shade but often also under sun; all were exposed to rain or tripling water; abundance respectively cover was highest when the wall aspect was eastern, south-eastern or south; on wall top and wall base joint abundance was substantial higher when maintenance was regular, whereas on vertical wall surface cover was similar for regular and seldom maintenance.

The top ten species (resp. genera for no further determined plants) present on most walls, over all wall elements, are displayed in Figure 8 and represent 12 % of all species found. Most of the species (62 %) have been found on one wall only, 15 % on two walls, 6 % on three walls and 5 % on four walls (Figure 9).

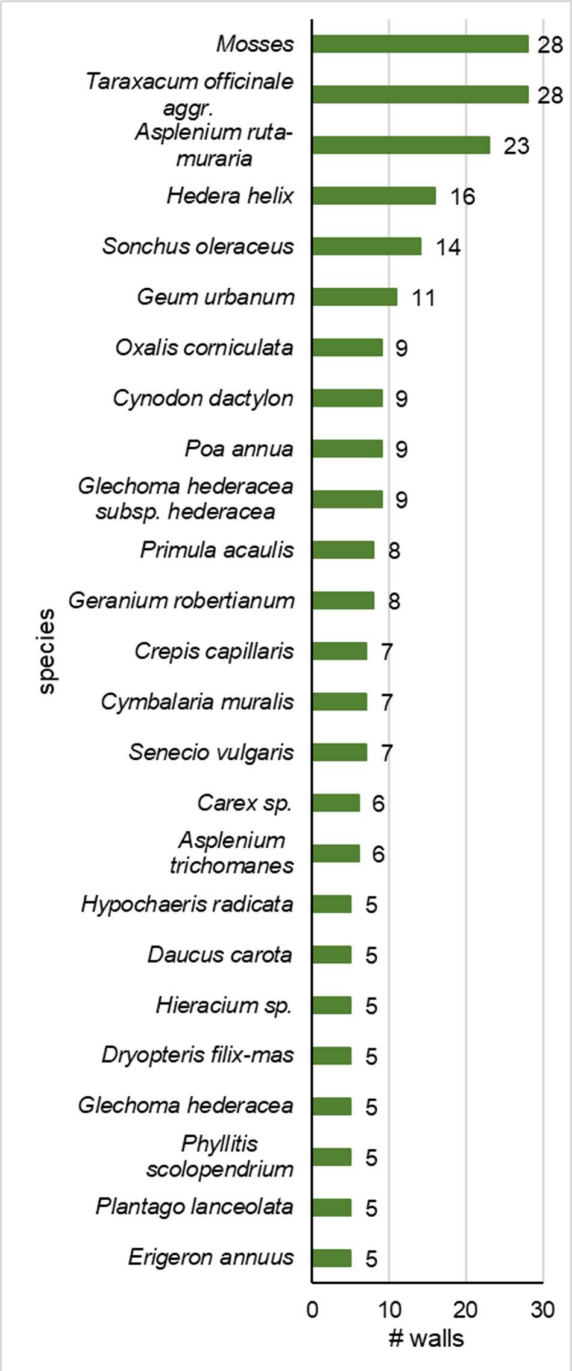



*Figure 8 Top ten species (or genera) over all three wall elements.*

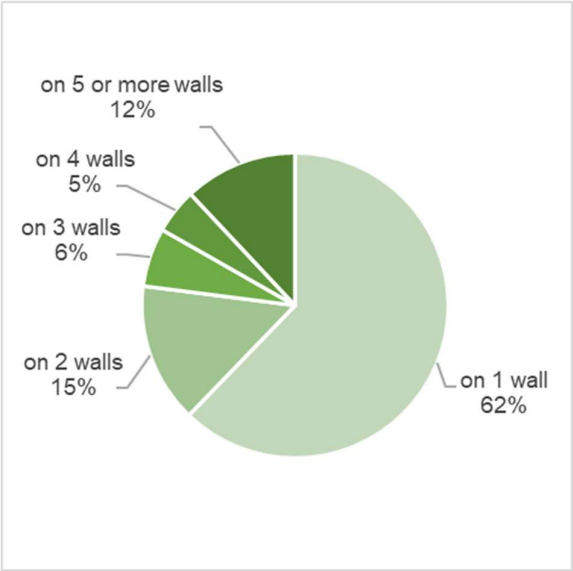



*Figure 9 Number of species per number of walls where they have been found in percent of total number of species over all three wall elements*

## 3.2. Wall top

### 3.2.1. Overview

On 11 walls transect relevés were done. Only two of these walls were less length than 8 m long and thus not 8 transect sections but only 7 resp. 5 transect sections could be assessed. In total 48 transect sections had vegetation and 41 different species / genera were recorded, 36 transect sections had no vegetation. In the transect sections 28 species were found, additional 13 species were found on the rest of the wall top (Table 9, Appendix 4).

*Table 9 Overview of the key figure related to the wall top relevés.*

| indicator | key figures |
|---|---|
| **# relevés** | 11 |
| **# transect sections with vegetation** | 48 |
| **# transect sections without vegetation** | 36 |
| **# species** (genera if species not defined) | 41 (28 in the transect sections, 13 other species present on the rest of the wall top) |
| **total abundance** | 129 in all transect sections |

35 species (85 % of all species) have been found on 1 wall only, three species (7 %) on two walls, two species (5 %) on three walls and mosses on 9 wall tops (3 %). Figure 10 displays the species on more than 1 wall. On the wall top 88 % of the species are native, 6 % archaeophyte and 6 % neophyte.

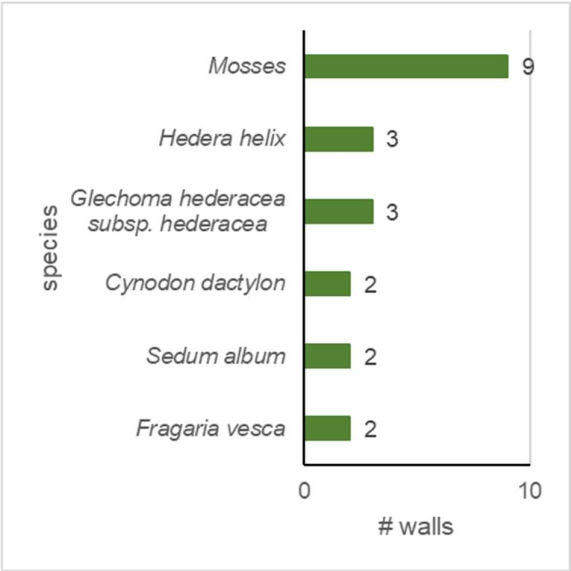



*Figure 10 Species present on more than one wall top.*

### 3.2.2. Species in the transect sections

Mosses, *Glechoma hederacea* subsp. *hederacea* and *Hedera helix,* which are present also on most walls (cf. Figure 8), showed the highest abundance on wall top followed by *Geranium robertianum* and *Cerastium fontanum,* both present on one wall only (Figure 11). Accordingly, the families with the highest abundance, mosses excluded, were Lamiaceae followed by Araliaceae and Geraniaceae (Figure 12).

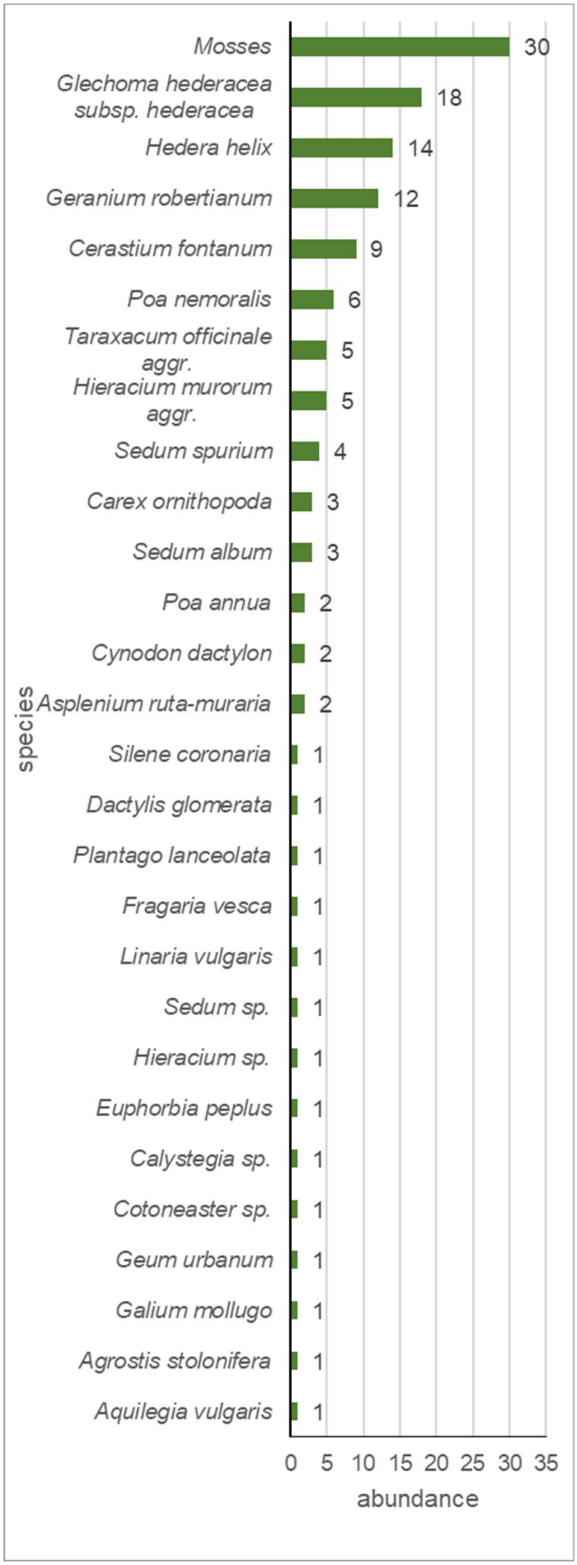



*Figure 11 All species and their abundance over all wall top transects.*

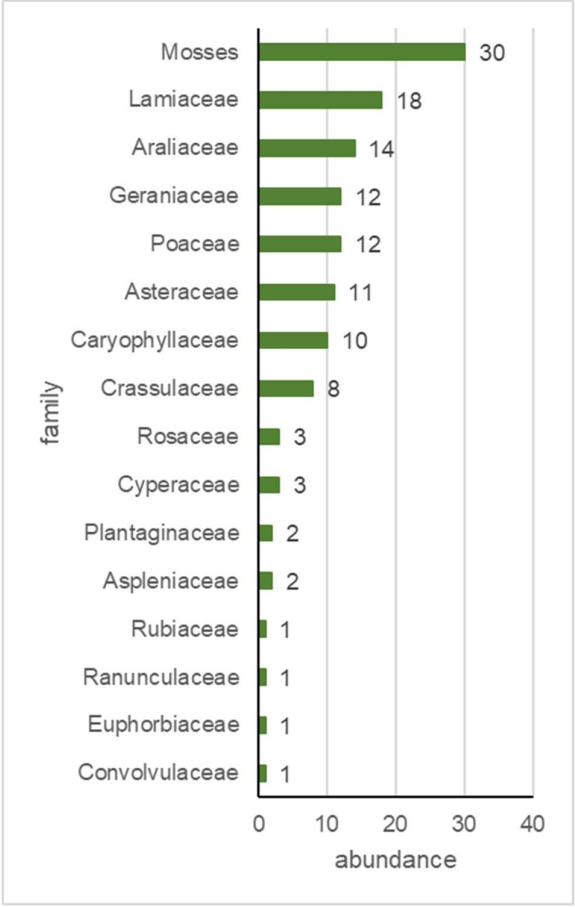



*Figure 12 Families and their species abundance over all wall top transects.*

Wall ID 20 has the wall top with the highest species richness in the plot area (six species, same as wall ID 12), the highest abundance (24, same as wall ID 30) and as well the highest mean species richness and mean abundance per transect section (**Appendix 7** Table 15, Figure 14).

Looking over all transect sections together, the mean species richness per transect section is 1.0 and the mean abundance is 1.5 (Figure 13).

*Figure 14 Wall ID 20 has the highest wall top species richness (photo: S. Caregnato).*

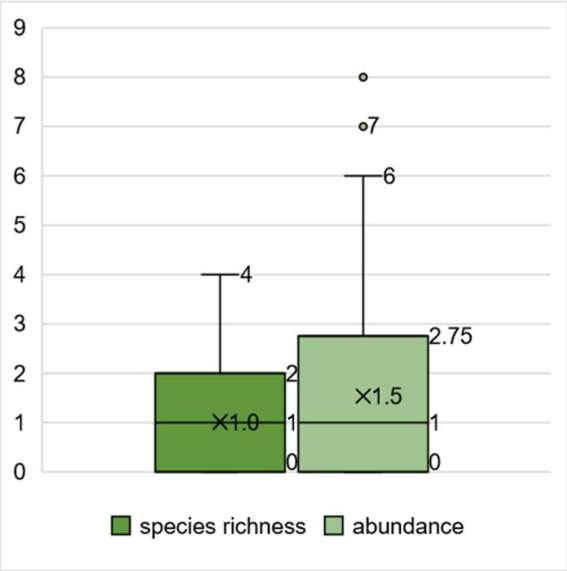



*Figure 13 Mean species richness and abundance over all wall top transect sections.*

### 3.2.3. Characteristics of the sprouting point

#### Surface position

The wall top as supporting surface was in 1 case inclined and for the remaining 10 walls horizontal. On the inclined wall top two species were found with total abundance of 10, on the horizontal one 27 with abundance of 119 (**Appendix 7** Table 16). On inclined wall tops the abundance in proportion to species richness is slightly higher than on vertical wall tops (Figure 15).

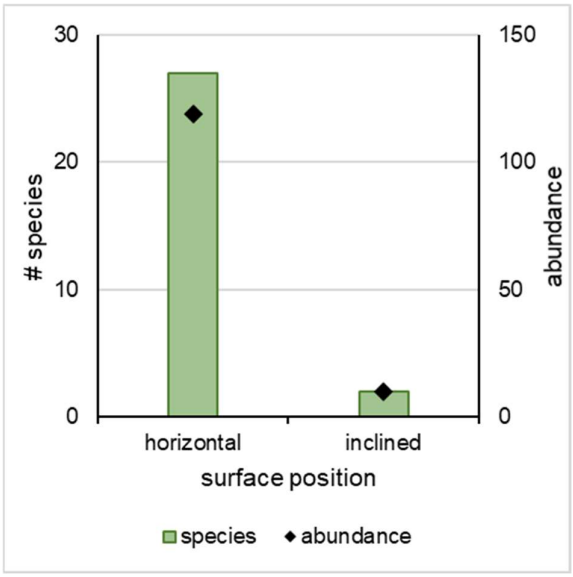



*Figure 15 Wall top: number of species (left axis) and their total abundance (right axis) with sprouting point on horizontal or inclined wall tops.*

#### Angle of the surface

The angle of surface is in general plane (Figure 16), the few cases of horizontal dihedral angle bottom are due to a retaining wall with balustrade (Figure 17) and the two species growing there were *Asplenium ruta-muraria* and *Hedera helix* (**Appendix 7** *Table 17*).

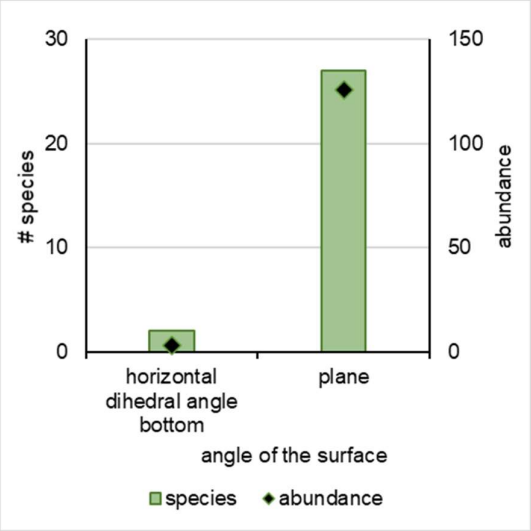



*Figure 16 Wall top: number of species (left axis) and their total abundance (right axis) per angle of the surface of the sprouting point.*

*Figure 17 Retainment wall with balustrade on the wall top of wall ID 8 (photo. S. Caregnato).*

## Texture

One wall top showed strong roughness and had apart of moss vegetation, three other species. All other wall top were of week roughness and had 25 species in total (**Appendix 7** *Table 18*, Figure 18). Only mosses were present on both texture types. No wall top of texture type smooth with vegetation has been found. Examples of roughness types see Figure 19.

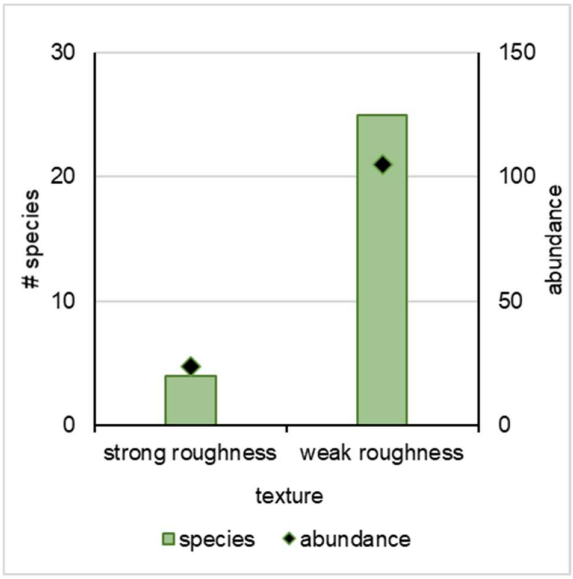



*Figure 18 Wall top: number of species (left axis) and their total abundance (right axis) per texture of the surface in the sprouting point.*

*Figure 19 Left example of strong roughness, right example of weak roughness on vertical wall surfaces (picture: S. Caregnato).*

### Form of sprouting point

Most species were found on joints (22 species), followed by pores (9 species) and by cracks (5 species). Abundance in proportion to species richness is highest with plants germinating on pores and mainly due to the mosses whereas it is lowest with plants germinating in joints (**Appendix 7** *Table 19*, Figure 20). **Appendix 7** *Table 20* displays the species found on all three types of form of sprouting point (*Glechoma hederacea* subsp. *hederacea*), on two or only one type of form of sprouting point. Cracks were found on plastered wall tops or wall tops made of sandstone or limestone, whereas pores on natural stone stones, limestone, granite and limestone.

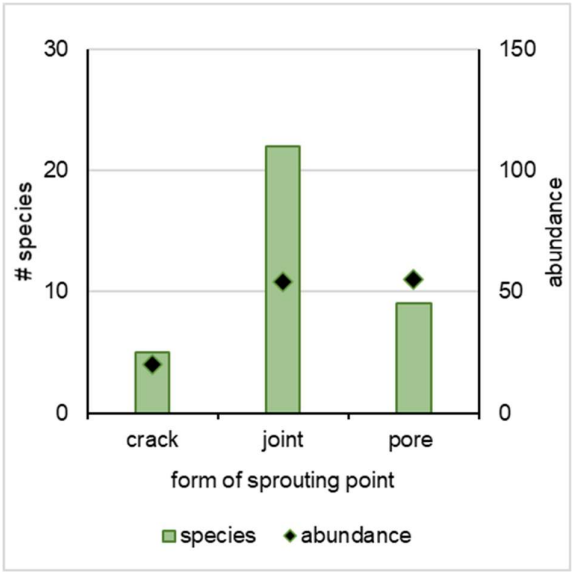



*Figure 20 Wall top: number of species (left axis) and their total abundance (right axis) per form of sprouting point.*

### Substratum

The plants germinated on three type of substrata earth accumulated over the wall top mostly in cracks/joints (11 species), masonry (17 species) and mosses (7 species, example see Figure 22). Abundance and abundance in proportion to species richness ist highest with the substratum masonry (Figure 21, **Appendix 7** Table 21). Species found only on one or on two substrata are listed in **Appendix 7** Table 22.

*Figure 22 Hieracium sp. growing on substratum moss on a wall top (picture: S. Caregnato).*

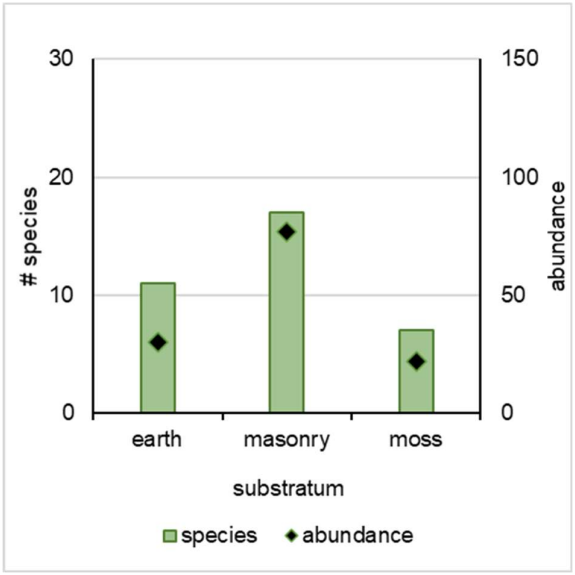



*Figure 21 Wall top: number of species (left axis) and their total abundance (right axis) per level of sun exposure.*

### Sun exposure

15 of the 28 species germinated under sun exposure, 13 under shade and 5 under shade. The abundance as well as abundance in proportion to species was highest in partial shade (*Table 23*, Figure 21). Mosses and *Glechoma hederacea* subsp*. hederacea* grew under all three sun exposure levels, whereas *Hedera helix* was found on sun exposed or partial shaded places, their abundance summarized represents almost 50 % of total abundance on wall tops. All other species were found on one sun exposure level only (Appendix 7 *Table 24*).

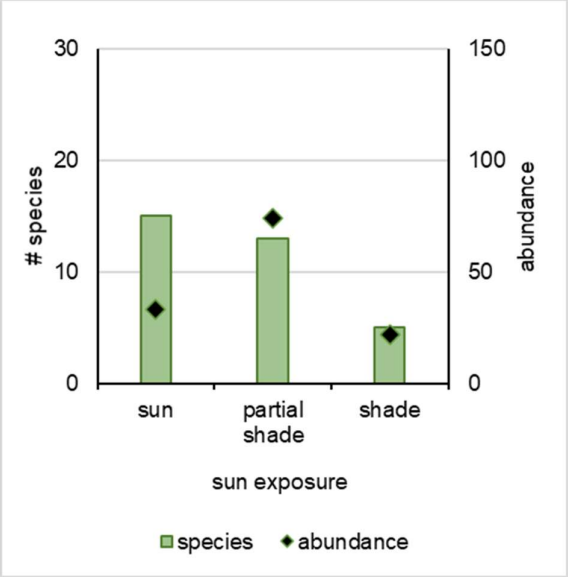



*Figure 23 Wall top: number of species (left axis) and their total abundance (right axis) per type of substratum.*

### Water exposure

The sprouting point for all species was exposed to rain.

## 3.3. Vertical wall surface

### 3.3.1. Overview

33 relevés were done and 116 different species / genera were found in total, 77 in the plot areas and 40 on the rest of the vertical wall surface. The total plot area is 130.7 $m^2$, the sum of vegetation cover is 18.5 $m^2$ (Table 10, Appendix 5).

*Table 10 Overview of the key figure related to the vertical wall surface relevés.*

| indicator | key figures |
|---|---|
| **# relevés** | 33 (3 on freestanding walls, 29 on retainment walls, 1 on civil constructions) |
| **# species** (genera if species not defined) | 116 (109 species, 8 genera) 76 in the plot areas 40 other species present on the rest of the vertical wall surface |
| **# families** | 31 |
| **total plot area** | 130.7 $m^2$ (32 walls with plot area 4 m2, 1 wall (wall ID 10) with plot area 2.7 m2) |
| **total area with vegetation cover** | 18.5 $m^2$ |
| **cover in % of plot area** | 14.161 |

The species present on most walls are displayed in Figure 24 and represent 10 % of the total species found. Ferns of the subclass *Polypodiidae* are well represented in this top ranking with four species (*Asplenium ruta-muraria, Asplenium trichomanes, Phyllitis scolopendrium* and *Dryopteris filix-mas*). Another fern found on a single wall is *Asplenium ceterach*. Most of the species (67 %) have been found on one wall only, 18 % on two walls, 3 % on three walls and 2 % on four walls.

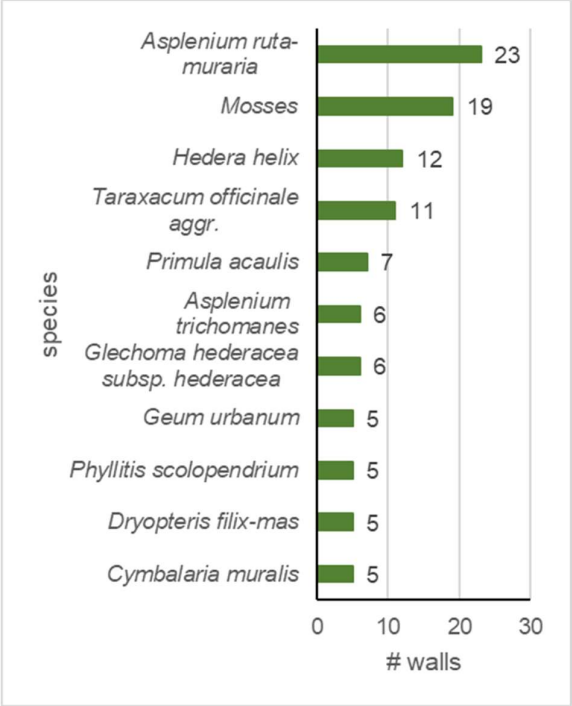



*Figure 24 Species present on more than 5 vertical wall surfaces*

### 3.3.2. Species in the plot areas

Considering only the records in all 33 plot areas the total cover of the vertical wall surface by the 76 species is rounded 14 %. Figure 26 displays 20 species with cover ≥ 0.1 % which account for 13.1 % of the total plant cover, whereas the remaining 51 species account only for 1.1 % (Figure 25). Overlapping of plant cover was seldom thus the resulting 85.6 % of vertical wall survey area not being covered by vegetation is deemed to be realistic. Families with cover ≥ 0.1 % are displayed in Figure 27. Not considering mosses, the Aspleniaceae are clearly leading with a total cover of 4.8 % of the total plot area.

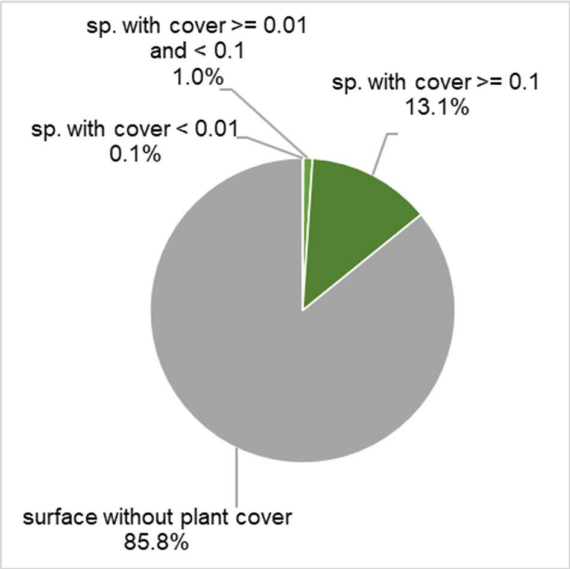



*Figure 25 Species and their cover in percent of the total survey area grouped in 3 cover levels (< 0.01 %; between 0.01 and 0.1; >= 0.1).*

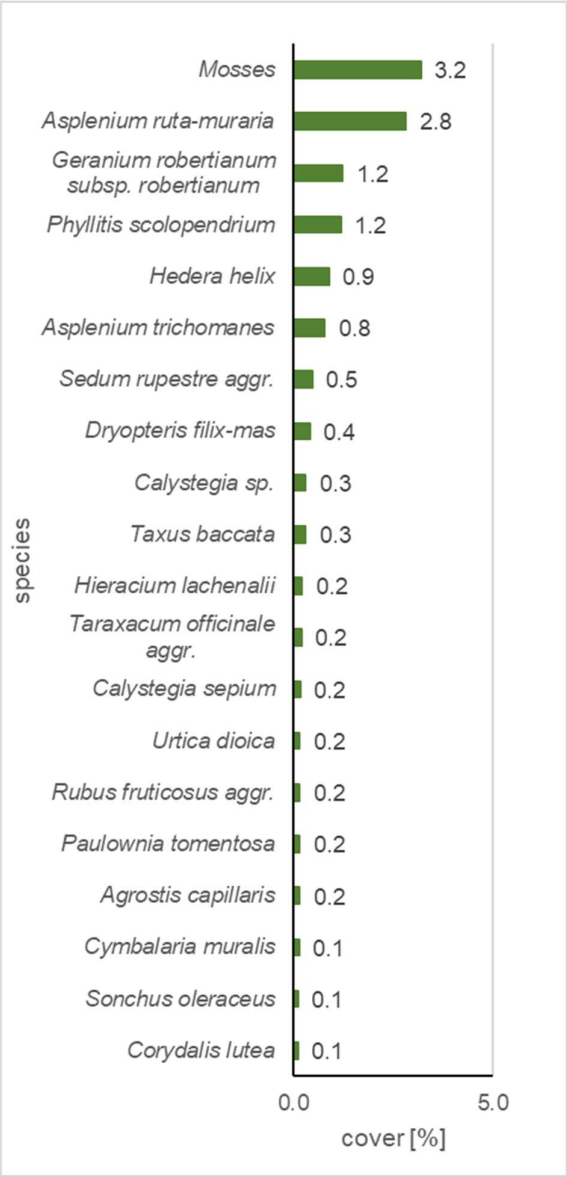



*Figure 26 Species with cover in percent of total survey area > 0.1 %.*

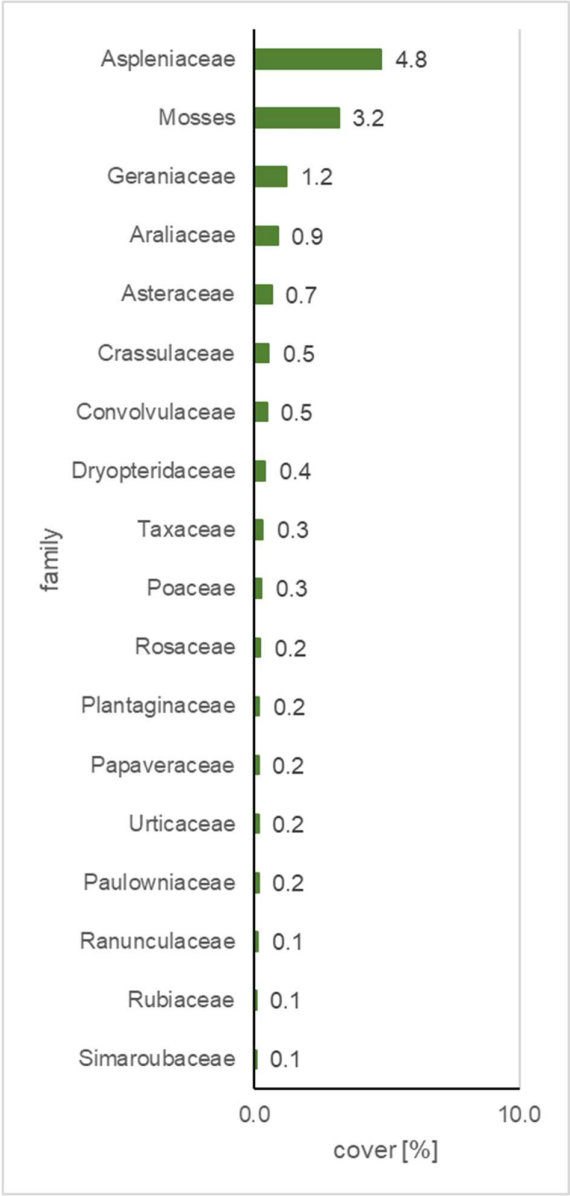



*Figure 27 Families with cover in percent of total survey area > 0.1 %.*

The walls with the highest species richness in the plot area is wall ID 29 with 12 species followed by wall ID 38 with 11 species (Appendix 7 Table 25). The highest cover in the plot area has been registered on wall ID 11 (mainly due to high cover with mosses: 2.8 $m^2$ out of total 3.08 $m^2$) followed by wall ID 2 (If only vascular plants are considered, wall ID 2 would rank first for species richness and cover as well. Cover in percent of the total survey area (= sum of all plot areas) amounted to 3.2 % for mosses, 4.0 % for ferns (4 species) and 7.0 % for all other vascular plants (71 species).

*Figure 28 From top left to bottom right: highest species richness on vertical wall surface on wall ID 29 followed by wall ID 38; highest cover on wall ID 11 followed by wall ID 2 (pictures: S. Caregnato)*

The mean species richness of the plots is 5 and the mean cover 0.56 $m^2$ (Figure 29).

The walls with the largest species richness have been found nearby the river Limmat (two walls) and in residential areas northern, western and southern of the city centre, see visualization of the species richness per wall Figure 30. The two walls with highest cover are nearby the Limmat and in residential area eastern of the city centre (Figure 31).

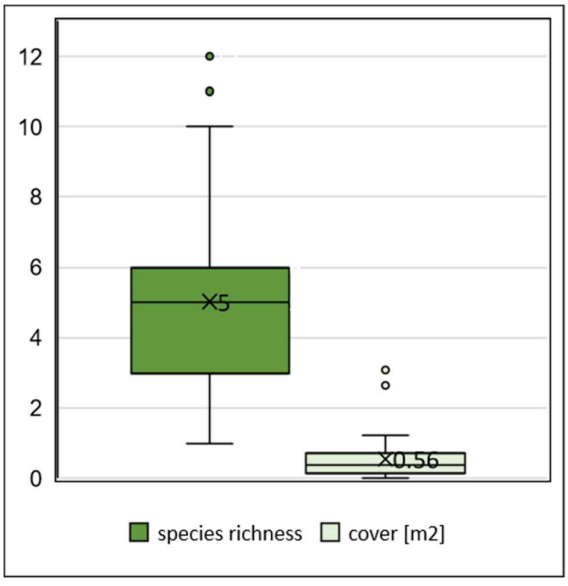



*Figure 29 Mean species richness and cover in m2*

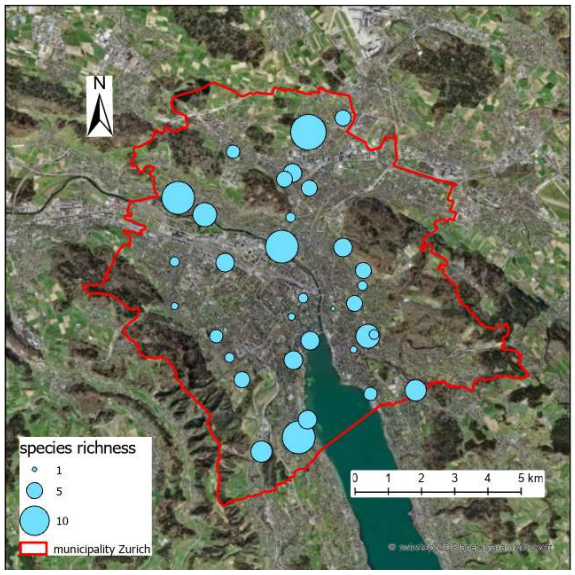



*Figure 30 Vertical wall surfaces: proportional visualization of species richness. Image: swisstopo, amended with data from the survey.*

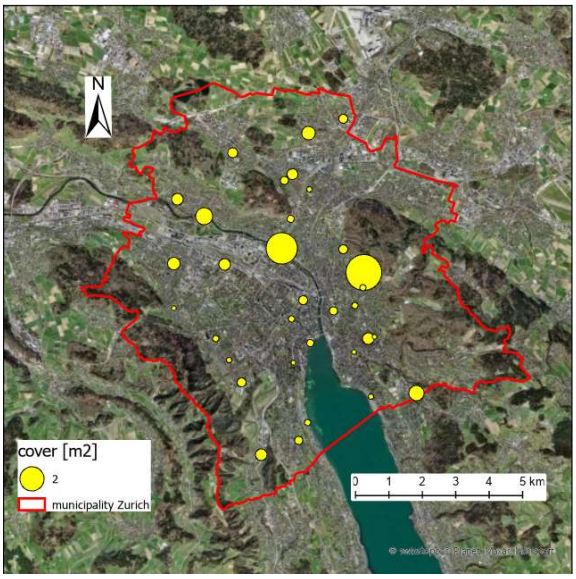



*Figure 31 Vertical wall surfaces: proportional visualization of cover [$m^2$]. Image: swisstopo, amended with data from the survey.*

### 3.3.3. Characteristics of the sprouting point

#### Surface position

The position was for 85 % of the sampled walls vertical and for 15 % inclined with retainment walls only in the last group. 61 species with a cover of 9.0 % of the total survey area were able to germinate on a vertical surface whereas 24 species with a cover of 5.2 % grew on an inclined one (10 species grew on vertical as well inclined surface) (Figure 32). Related to coverage, ferns are leading the top ten species on vertical walls, whereas they are almost not present on inclined walls (see top ten species per surface position type in Appendix 7 Table 26 and top then species present on both position types in Appendix 7 Table 27).

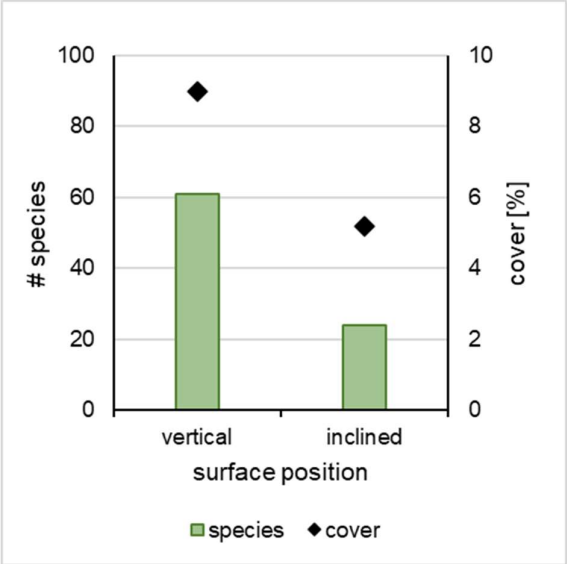



*Figure 32 Vertical wall surface: number of species (left axis) and their cover (right axis; in percent of total survey area) with sprouting point on vertical or inclined position.*

### Angle of the surface

Bearing in mind that the plot areas have been selected based on highest plant coverage most of the species (74) germinated on the plane surface of the wall (Figure 33 and Appendix 7 Table 28). The three freestanding walls were all in this group. Only one side of the wall qualified for a relevé and their aspect was either northeast, north or northwest. The species growing on their plane surface were, ordered descending by cover, *Hedera helix*, Mosses, *Asplenium ruta-muraria, Asplenium trichomanes, Dryopteris filix-mas* and *Poa pratensis* aggr.

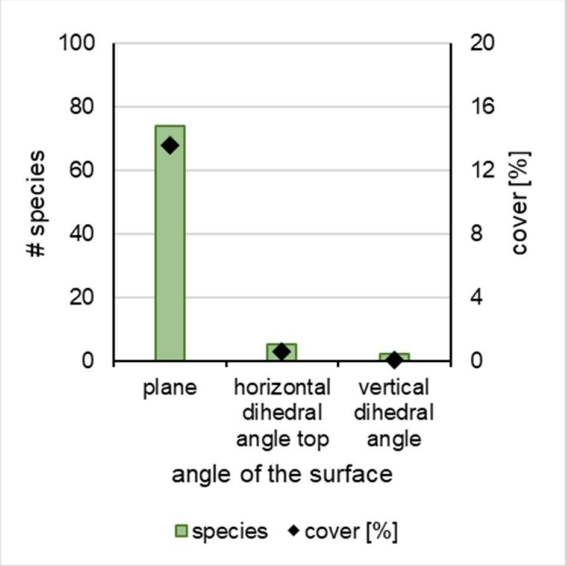



*Figure 33 Vertical wall surface: number of species (left axis) and their cover (right axis; in percent of total survey area) per angle of the surface of the sprouting point.*

Horizontal dihedral angle top on vertical wall surfaces is generally given by the cover plate on the wall top (Figure 34). 16 out of the 33 walls had such a cover plate and 7 plots had plants growing in the dihedral angle top. All 7 plots were on retainment walls, all except one were exposed to sun and almost all aspects were represented. The species were *Asplenium ruta-muraria,* showing by far the highest cover*,* followed by *Calystegia sepium, Hedera helix, Convallaria majalis* and *Circaea lutetiana*. *Asplenium ruta-muraria* is the only species adapted well to bright light and moderate dry conditions whereas the other species need more moist and shady environments.

Vertical dihedral angles have been found seldom on the walls and were even more seldom part of plot areas. Two plots with each one species, *Asplenium ruta-muraria* and *Taraxacum officinale* aggr. have been registered (Figure 35), in both cases the surfaces forming the angle are of different materials i.e., represent a joint. Horizontal dihedral angle bottom is not represented as none of the plots showed such a geometrical structure. The top ten species per angle of the surface listed in Appendix 7 Table 28 account for 80 % of the total cover of 14.161 % whereas the species growing in two or three type of angle of surface as listed in Table 29 account for 37 %.

*Figure 34 Example of plants with sprouting point on horizontal dihedral angle top on wall ID 18 (photo: S. Caregnato).*

*Figure 35 The two species found on vertical dihedral angle: left Asplenium ruta-muraria on the retainment wall ID 16 and right Taraxacum officinale aggr. on bridge pilaster of wall ID 26 (photo: S. Caregnato)*

**Texture**

24 % of the walls had a strong roughness, 76 % a weak roughness and none were smooth. The cover in proportion to species richness is slightly higher when the material of the wall is of strong roughness (Figure 36). Appendix 7 *Table 30* displays the top ten species per texture type and Appendix 7 *Table 31* the species growing on both types of texture.

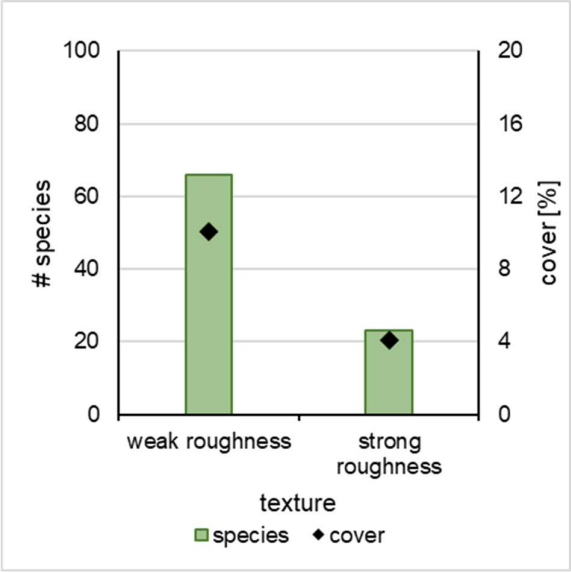



*Figure 36 Vertical wall surface: number of species (left axis) and their cover (right axis; in percent of total survey area) per texture of the surface in the point of germination.*

### Form of sprouting point

67 species were found in the joint between two material of the wall, 8 species in pores and as well 8 in cracks (Figure 37). Cover in proportion to species richness is highest with sprouting point pore as mosses are ranking top in this category ( Figure 37, Appendix 7 *Table 32*). *Asplenium ruta-muraria*, which figures second regarding coverage over all plot areas (refer to Figure 26), was found in all three form of sprouting point types , *Corydalis lutea* and *Gallium mollugo* in joints and cracks, *Geum urbanum, Primula acaulis* and mosses in joints and pores (Appendix 7 Table 34). Cracks were found on plastered vertical wall surfaces or walls made of sandstone, limestone and in one case of concrete bricks. Pores were found on sandstone and on plastered surfaces.

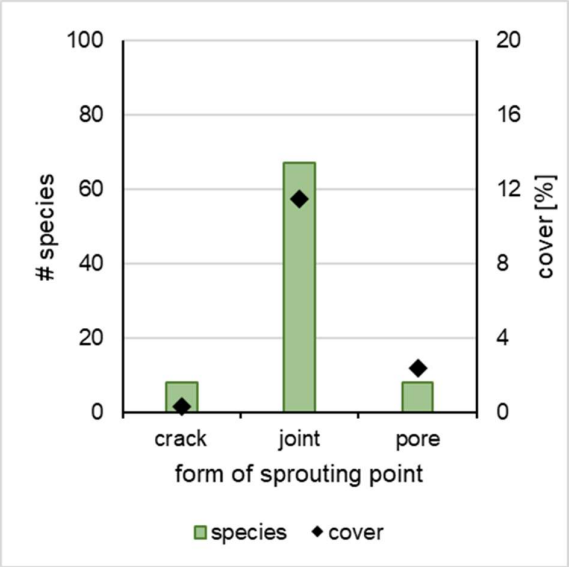



*Figure 37 Vertical wall surface: number of species (left axis) and their cover (right axis; in percent of total survey area) per form of sprouting point.*

### Substratum

Most species (63) germinated in the masonry followed by loose filling material with 15 species present in the joints of two natural stone walls without mortar, mosses in joints with 4 and earth in joints with 3 species. Cover in proportion to species richness was highest with earth, followed by loose filling material, masonry and mosses (Figure 38). Top ten species per substratum type are displayed in Appendix 7 Table 34 and species growing in more than one substratum type in Appendix 7 Table 35.

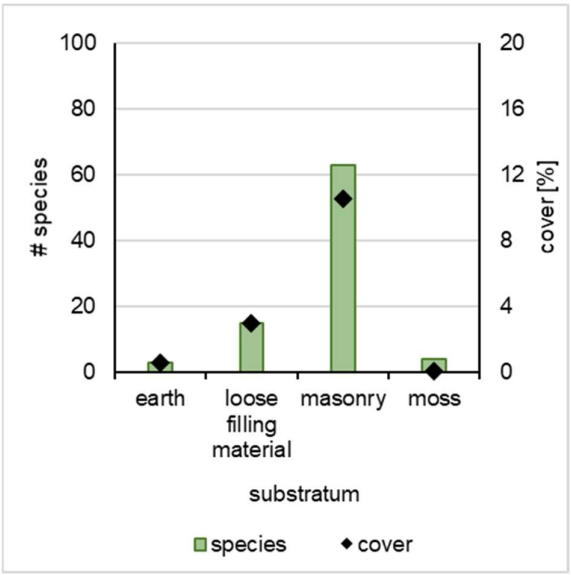



*Figure 38 Vertical wall surface: number of species (left axis) and their cover (right axis; in percent of total survey area) per type of substratum.*

### Sun exposure

Highest number of species germinated under sun and in partial shade, in both cases 41 species, whereas 19 species were registered in shaded areas. Cover in proportion to species richness was highest under sun exposure, followed by partial shade and finally shade (Figure 39). Mosses showed their highest cover under partial shade (2.6 %), ferns were present with almost the same cover on sun and partial shade places (1.6 respectively 1.7 %) and on full shade places they

showed the highest cover of 0.7 %. *Asplenium ruta-muraria* was the predominant species followed by *Phyllitis scolopendrium*, both growing under all three level of sun exposure. *Asplenium trichomanes* showed larger cover on partial shaded places than on shaded locations, whereas *Dryopteris filix-mas* vice-versa. All other vascular plants together had the highest cover under high level of sun exposure (Figure 40) with predominance of *Geranium robertianum* subsp. *robertianum* (1.2 2 %). Top ten species per sun exposure type are displayed in Appendix 7 *Table 36*. *Asplenium ruta-muraria, Phyllitis scolopendrium* and *Hedera helix* have germinated under all three sun exposure levels (Appendix 7 *Table 37*).

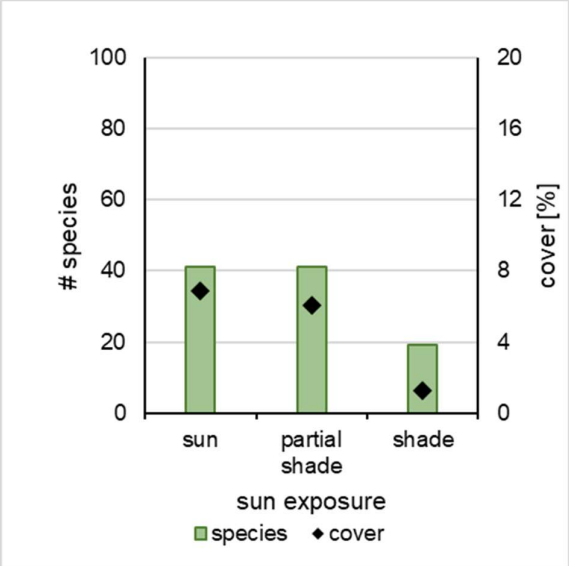



*Figure 39 Vertical wall surface: number of species (left axis) and cover (right axis; in % of total survey area) per sun exposure level.*

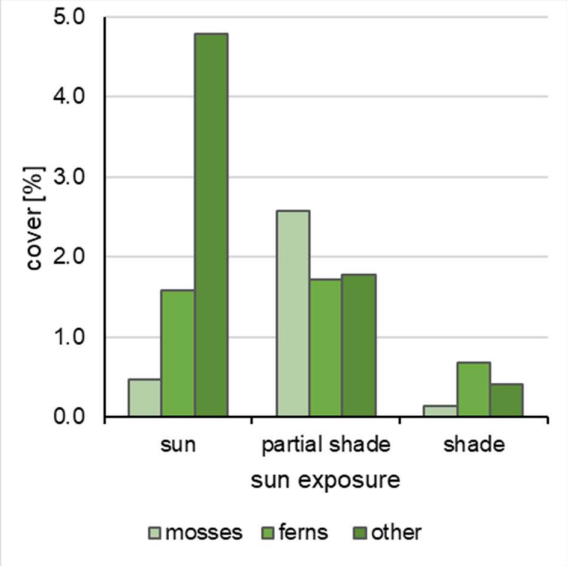



*Figure 40 Vertical wall surface: Cover in % of total survey area per sun exposure level for mosses, ferns and other vascular plants.*

### Water exposure

The sprouting point of 69 species was exposed to rain, 13 species were exposed to trickling water only and 10 species germinated in places which were covered. Cover in proportion to species richness was highest for sprouting points exposed to rain followed by points exposed to trickling water and very low with points covered (Figure 42).). Top ten species per water exposure type are displayed in Appendix 7 *Table 38*. Mosses and *Asplenium ruta-muraria* occur under all three water exposure conditions (Appendix 7 Table 39). Mosses, ferns and all other vascular plants showed the highest cover when exposed to rain. Mosses were almost not present under trickling water exposure or sheltered conditions. Vascular plants were present under trickling water exposure and to a low extend also under sheltered conditions (Figure 41). The 10 species growing under sheltered conditions (Appendix 7 Table 40) grew all on retainment walls (5 walls) and the cover was given by the cover plate overlapping partially the vertical wall surface, see example Figure 34. Their cover of

0.2 % is much smaller than the 1.7 % cover of species exposed to trickling water with similar number of species (13).

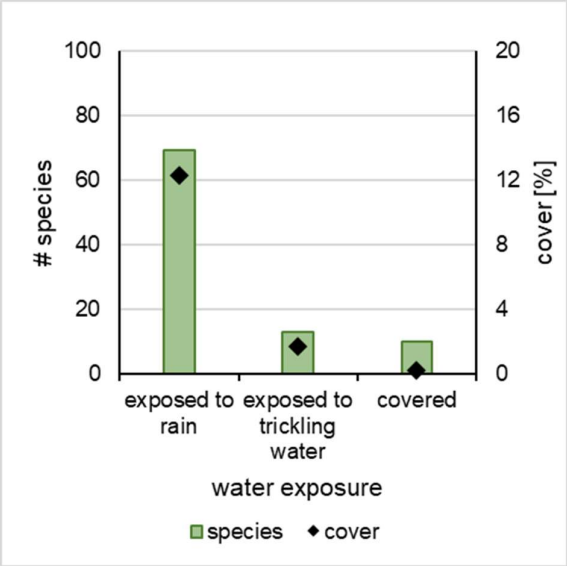



*Figure 42 Vertical wall surface: number of species (left axis) and cover (right axis; in % of total survey area) per water exposure level.*

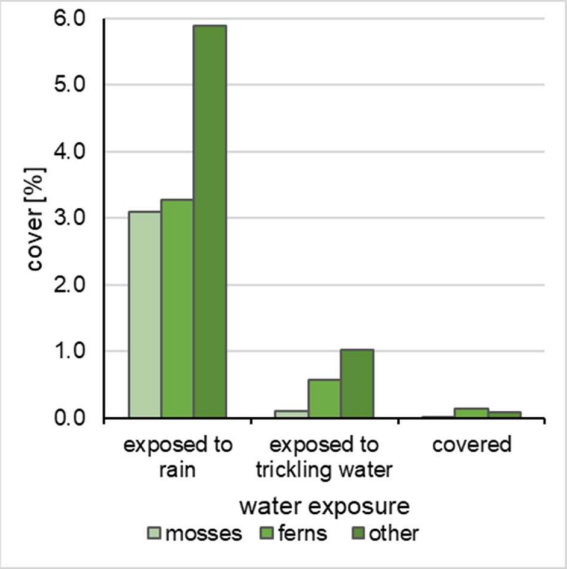



*Figure 41 Vertical wall surface: cover in % of total survey area per water exposure level for mosses, ferns and other vascular plants*

## Aspect

Mean species richness is highest for walls with north-western aspect with 5.7 species, though the mean cover is quite low with 12 % of the plot area. The highest mean cover have walls with western aspect (38 %) which also have the second highest mean species richness (5.3). Lowest species richness and cover have walls with south-western aspect with 2.0 species respectively 3 % cover.

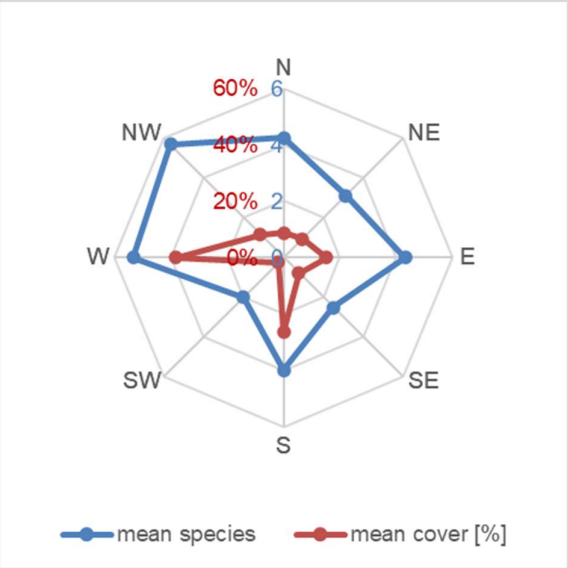



*Figure 43 Vertical wall surface: mean number of species and mean cover [%] per aspect*

Walls with western, north-western, northern and north-eastern aspect show highest cover values by ferns (Aspleniaceae and Dryopteridaceae) and mosses. Aspleniaceae are also leading in the other aspects except for walls with southern aspect where Geraniaceae, Crassulaceae and Convolvulaceae show higher cover (Appendix 7 Table 41).

### 3.3.4. Minimal adequate multiple regression model for species richness and cover [m²]

Correlation was found between the height of the wall and the wall inclination with │R │ = 0.76260801, for the subsequent analysis the height of the wall was ignored and only the wall inclination as well as the no or low correlated predictors were considered.

**Species richness** No quadratic term resulted to be significant. Also, no interaction with one or two other predictors showed to have a significant influence on species richness. Consequently, the full model was run with the linear predictors inclination, height relevé, length base joint, type of wall, aspect, maintenance and material. Simplifying the model resulted in no predictor having a significant influence on species richness.

**Cover** No quadratic term resulted to be significant. The full model was run same as for species richness with the linear predictors inclination, height relevé, length base joint, type of wall, aspect, maintenance and material. The simplified model showed, that the height of the relevé and that inclination have a highly significant influence on cover Table 11.

*Table 11 Statistical parameters of simplified multiple regression model [ lm(cover~height relevé + inclination) ]; p-values: p < 0.05 = significant (*), p < 0.01 = highly significant (**), p < 0.001 = very highly significant (***), p ≥ 0.05 non-significant (n.s.).*

| simplified model | estimate | p-value |
|---|---|---|
| intercept | 0.124 | 0.336 |
| height relevé | 0.735 | 0.002 ** |
| inclination | 0.028 | 0.004 ** |

8 different interactions with two or three predictors, as listed in Table 12, had a significant impact on cover when testing the simplified model with permutation of three-predictors-variable interactions. The different significant interactions added to the simplified model generated models with different $R^2$ and adjusted $R^2$ values (Table 12). Model no. 6 had the highest adjusted $R^2$ value of 0.865 but has not been considered as best model as due to the high number of levels of the aspect and limited number of samples not all coefficients could be estimated. Thus model no. 7 with the second best adjusted $R^2$ value of 0.723 resulted as best and final model.

*Table 12 Impact on cover: significant interactions with two or three predictors, R2 and adjusted R2 of the simplified model (model no. 1) and the more complex model with the interaction.*

| | model with interaction | | |
|---|---|---|---|
| significant interaction | model no. | $R^2$ | adjusted $R^2$ |
| | 1 | 0.469 | 0.434 |
| length base joint * inclination | 2 | 0.515 | 0.446 |
| height relevé * inclination | 3 | 0.570 | 0.526 |
| height relevé * aspect | 4 | 0.801 | 0.603 |
| height relevé * maintenance | 5 | 0.710 | 0.669 |
| height relevé * inclination * aspect | 6 | 0.975 | 0.865 |

| | | | |
|---|---|---|---|
| height relevé * inclination * maintenance | 7 | 0.784 | 0.723 |
| inclination * material | 8 | 0.798 | 0.691 |
| height relevé *material | 9 | 0.706 | 0.552 |

The final model included the linear predictors height relevé, inclination and maintenance along with the interaction between these three predictors. In this model, p-values of intercept and the interaction height relevé*inclination*maintenance were significant (Table 13). The adjusted R-squared was 0.723, i.e., 72.3% of the variance found in the response variable (species richness) can be explained by the minimal adequate multiple models. Residual plots can be found in the Figure 44.

The parameters of this final model showed that increasing height of the relevé, inclination and seldom maintenance (cleaning of wall/cutting of plants) had a positive effect on species cover as well as the interaction of elevation with inclination and maintenance (Table 13).

*Table 13: Statistical parameters of final minimal adequate multiple regression model for cover [ lm( cover ~ height relevé + inclination + maintenance + height relevé*inclination*maintenance ] p-values: p < 0.05 = significant (*), p < 0.01 = highly significant (**), p < 0.001 = very highly significant (***), p ≥ 0.05 non-significant (n.s.)*

| **Final model** | | |
|---|---|---|
| coefficients | value | p-value |
| intercept | 0.323 | 0.016 * |
| height relevé | 0.072 | 0.820 |
| inclination | 0.009 | 0.465 |
| maintenance.seldom | 0.242 | 0.405 |
| height relevé*inclination | -0.003 | 0.927 |
| height relevé*maintenance.seldom | 0.102 | 0.872 |
| inclination*maintenance.seldom | -0.088 | 0.074 |
| height relevé*inclination*maintenance.seldom | 0.162 | 0.041 * |
| $R^2$ | 0.784 | |
| adjusted $R^2$ | 0.723 | |
| p-value of the model | | < 0.001 |

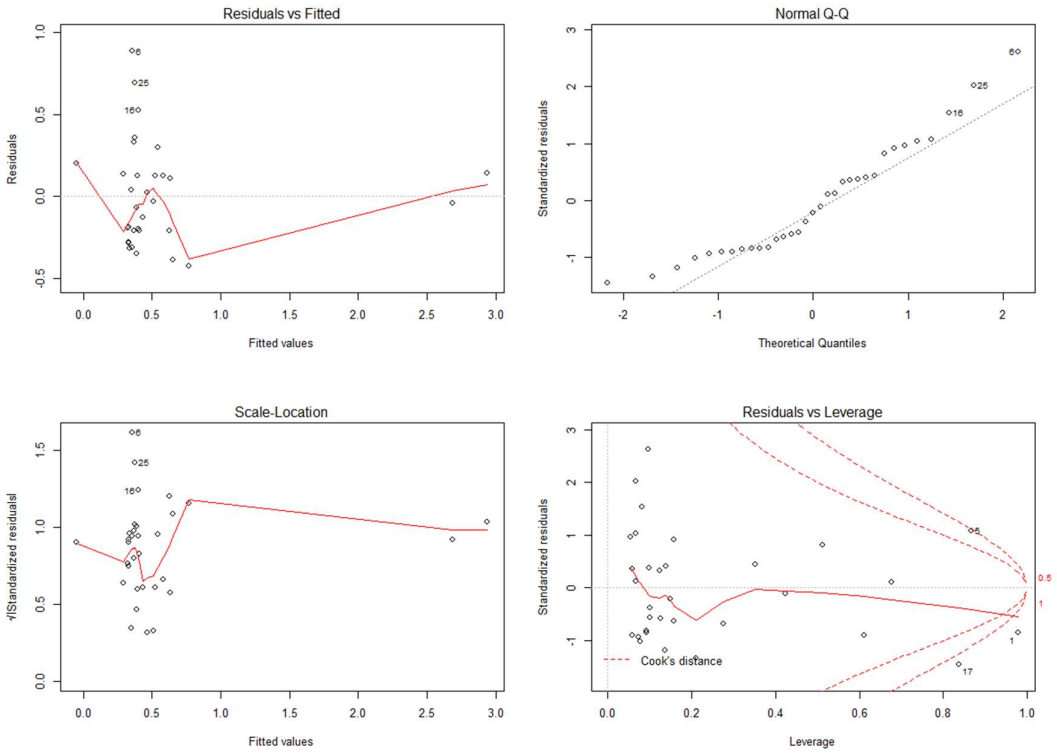



*Figure 44 Residual plot of the final model*

Figure 45 top three charts show the three interaction factors with the influence on species cover for each factor when the other 2 factors remain constant in the final model.

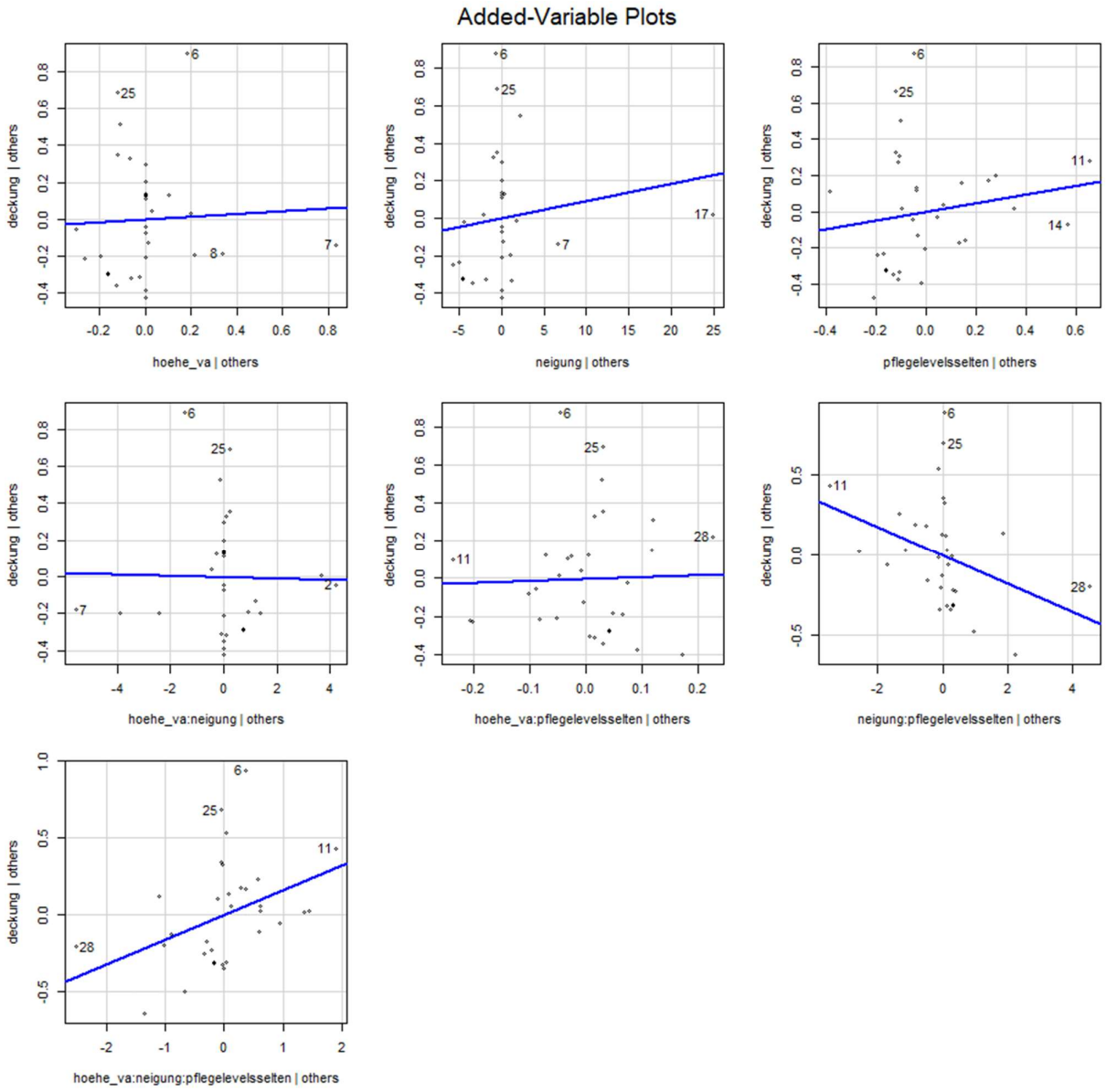



*Figure 45 Final model: effect of factors and interactions on cover*

## 3.4. Wall base joint

### 3.4.1. Overview

31 wall base joint relevés were done. 19 relevés had 8 transect sections, 12 relevés less than 8. In total 188 transect sections had vegetation and 146 species / genera were recorded. 29 transect sections hosted no plants. 124 species with a total abundance of 1040 were recorded in the transect section. 22 other species were recorded in the remaining part of the wall base joint (Table 44, Appendix 6).

*Table 14 Overview of the key figure related to the wall base joint relevés.*

| indicator | key figures | | |
|---|---|---|---|
| **# relevés** | 31 | | |
| **# transect sections with vegetation** | 188 | | |
| **# transect sections without vegetation** | 29 | | |
| **# species** (genera if species not defined) | 146 | 124 in the transect sections | 22 other species present on the rest of the wall top |
| **abundance** | | 1040 in the transect sections | |

Most species (70 %) were only present on one wall, species present on two walls represent 11 %, on three wall 7 %, on four walls 5 % and 10 species present on five or more walls represent 7 % of the species found and are displayed in Figure 46. On the wall base joint 85 % of the species are native, 12 % archaeophyte, 1 % are aggregate or species with subspecies that contain native plants as well as archaeophytes, 3 % are aggregate or species with subspecies that contain native as well as neophytes and 19 % are neophytes.

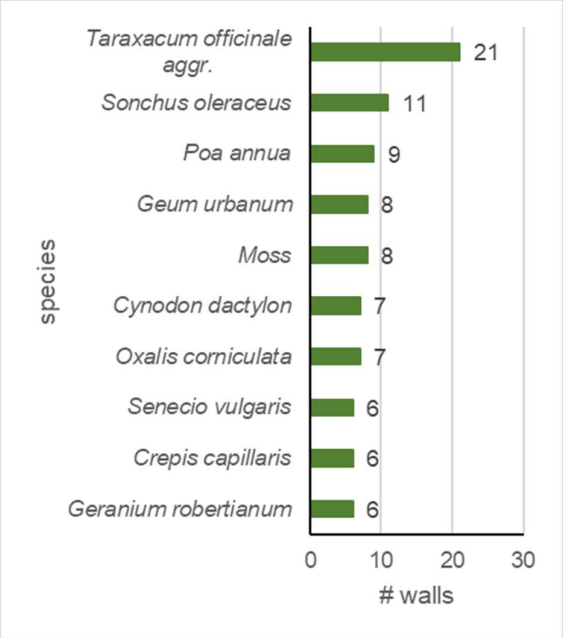



*Figure 46 Species present on more than one wall base joint.*

### 3.4.2. Species in the transect sections

*Taraxacum officinale* aggr., being present on most walls (Figure 46), is as well ranking on the first place when it comes to abundance with 243 single plants found (Figure 47), six times more as the second placed species, *Setaria viridis*. The family with the highest abundance is Asteraceae, followed by Poaceae and Rosaceae (Figure 48).

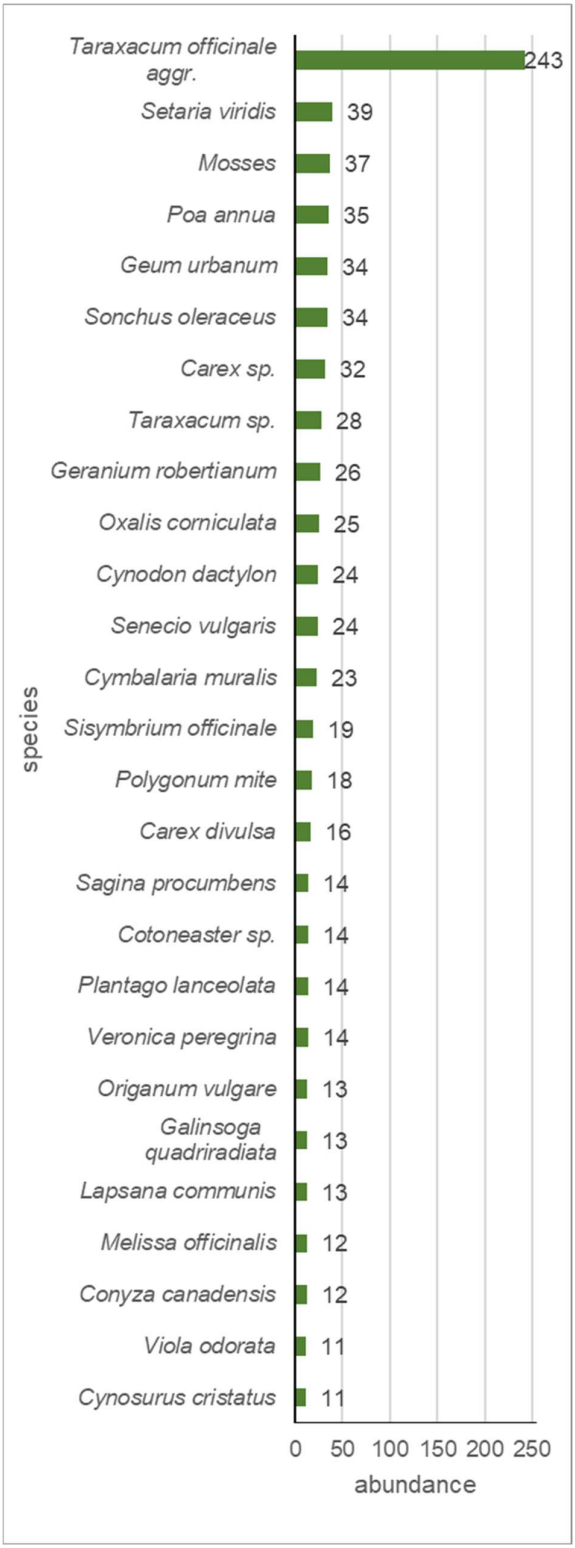



*Figure 47 Species with abundance > 10 over all wall base joints transects.*

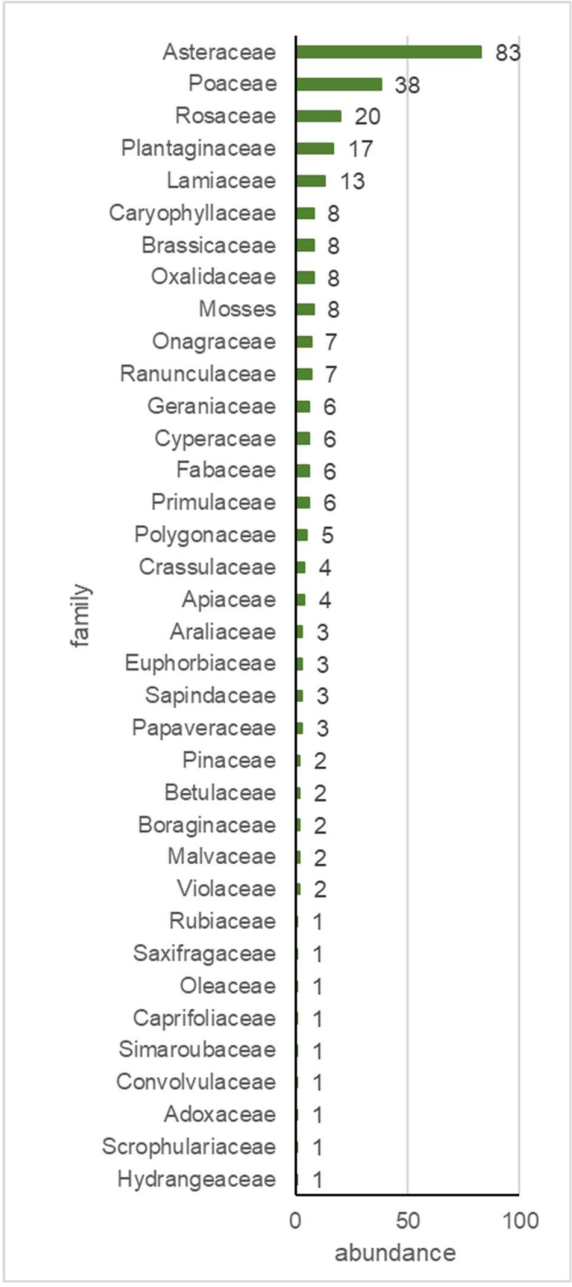



*Figure 48 Families and their abundance.*

With each 16 species the wall ID 22 and 33 have the highest species richness in the plot area. The highest abundance has been registered on wall ID 23 with 102. The highest mean species

richness per transect sections is on wall ID 1 with 6 species, the highest mean abundance per transect section is with wall ID 23 (Appendix 7 Table 42, Figure 49).

*Figure 49 Left wall ID 22, right top down: wall ID 33, 23 and 1 (pictures: S. Caregnato)*

The mean species richness over all transect sections assessed is 2.1 whereas the mean abundance is 4.8 (Figure 50).

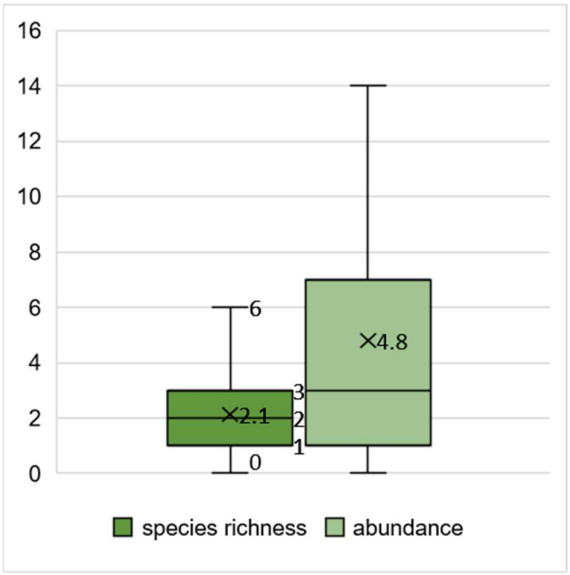



*Figure 50 Mean species richness and abundance over all wall base joint transect sections.*

### 3.4.3. Characteristics of the sprouting point

#### Surface position

Two wall base joint were inclined, the remaining 29 wall base joints (94 %) were horizontal. 13 species with abundance of 28 grew on an inclined base, 117 species with abundance of 1012 on horizontal base. The abundance in proportion to species richness was higher for species on horizontal base (Figure 51, Appendix 7 Table 43). Species found on both base categories are displayed in Appendix 7 Table 44.

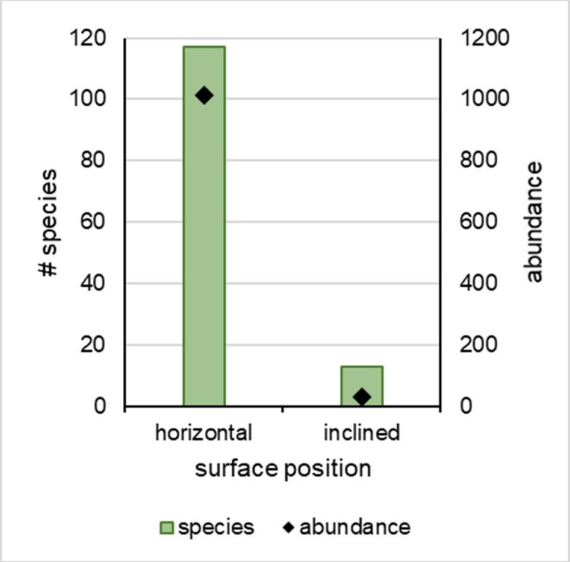



*Figure 51 Wall base joint: number of species (left axis) and their total abundance (right axis) with sprouting point on horizontal or inclined surface*

#### Angle of the surface

For all plants the angle of the surface was horizontal dihedral angle bottom.

#### Texture

25 species with abundance of 80 grew on a base of strong roughness and 116 species with abundance of 960 on a base of weak roughness. The proportion from abundance to species richness was higher with texture weak roughness ( Figure 52, Appendix 7 Table 45). Appendix 7 Table 46 displays the species found on both texture types.

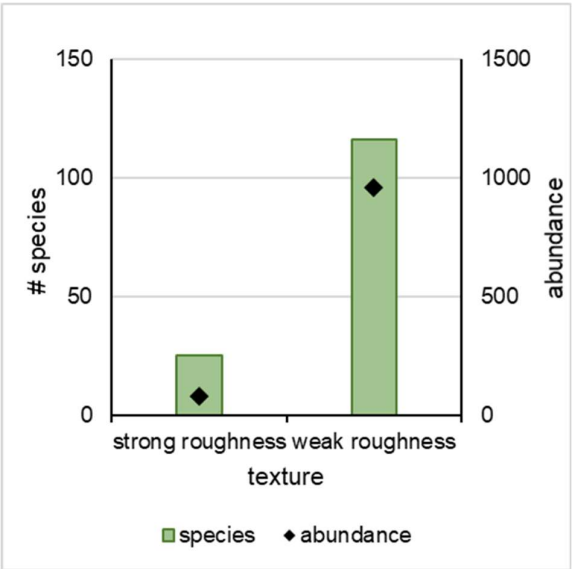



*Figure 52 Wall base joint:number of species (left axis) and their total abundance (right axis) per texture of the surface in the point of germination.*

### Form of sprouting point

The joint is the primary form of sprouting point type of the wall base joint (having most species and highest abundance) however in some few cases there were cracks on the horizontal pavement adjacent the wall base (4 species, abundance of 5). Abundance in proportion to form of sprouting point is highest with joint (Figure 53, Appendix 7 *Table 47*). Species germinating on both type of form of sprouting point are *Carpinus betulus, Taraxacum officinale* aggr. and *Polygonum aviculare* (Appendix 7 *Table 48).*

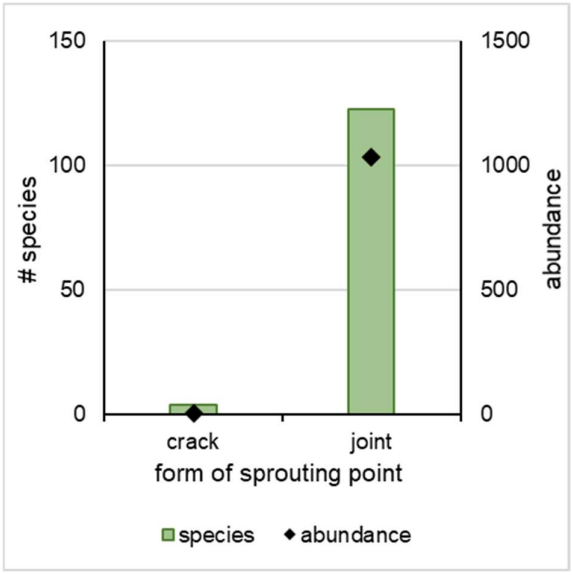



*Figure 53 Wall base joint: number of species (left axis) and their total abundance (right axis) per form of sprouting point.*

### Substratum

92 species with abundance of 596 germinated on earth and 6 on loose filling material (abundance 23), in 58 cases (abundance 421) the substratum could not be properly determined as the joint was too narrow. Abundance in proportion to species was highest where the substratum was not visible, followed by earth and loose filling material (Figure 54, Appendix 7 *Table 49*). Appendix 7 *Table 50* shows the species found in both substrata.

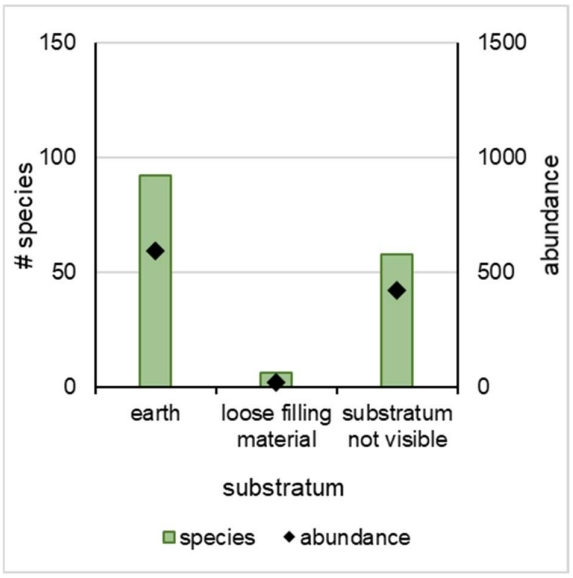



*Figure 54 Wall base joint: number of species (left axis) and their total abundance (right axis) per type of substratum.*

### Sun exposure

78 species germinated exposed to sun, 59 in partial shade and 25 in shade. The abundance as well as abundance in proportion to species richness was highest for the exposure level sun narrowly followed by partial shade. Less species and lower abundance, also in proportion to each other, was found for plants germinating in shade (Figure 55). Top then species per sprouting point are listed in Appendix 7 *Table 51* and species growing on more than 1 sun exposure level in Appendix 7 *Table 52*. *Taraxacum officinale* aggr. is predominant under all three exposure levels, particularly under direct sun exposure.

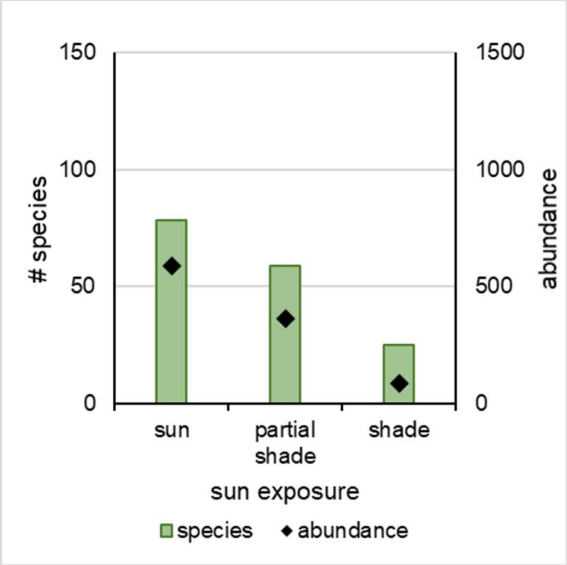



*Figure 55 Wall base joint: number of species (left axis) and their total abundance (right axis) per level of sun exposure.*

### Water exposure

120 species were exposed to rain (abundance 982) and 11 species (abundance 58) to trickling water. Abundance in proportion to species richness was higher for species exposed to rain (Figure 56). Top ten species per exposure level to water are displayed in Appendix 7 *Table 53*, species found on both exposure types in Appendix 7 *Table 54*.

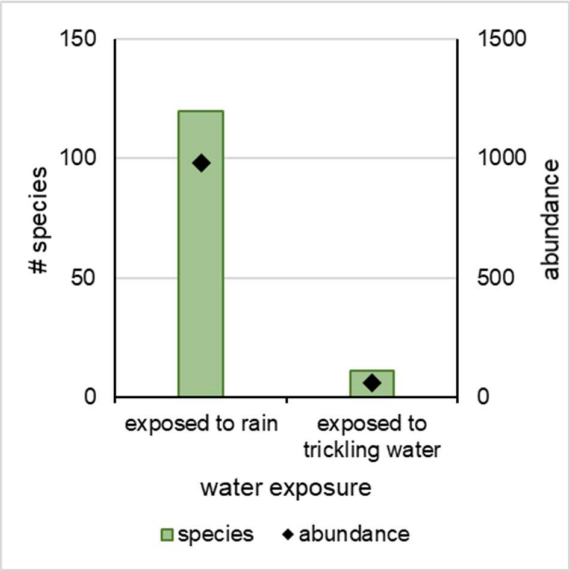



*Figure 56 Wall base joint: number of species (left axis) and their abundance (right axis) per water exposure level.*

### Joint size

89 species with abundance 748 were found in wall base joints < 0.5 cm on 22 walls, 60 species with abundance 292 in joints ≥ 0.5 cm on 11 walls. Abundance in proportion to species richness was higher for the smaller base joints Figure 57. Top ten species per joint size are listed in Appendix 7 *Table 55*, species found in both joint sizes in Appendix 7 *Table 56*.

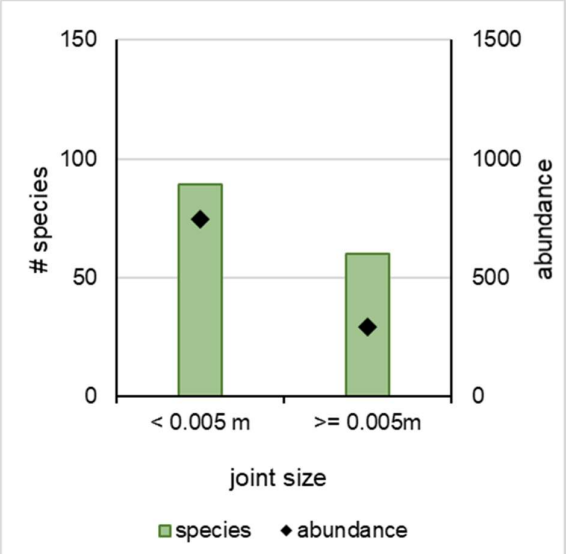



*Figure 57 Wall base joint: number of species (left axis) and their abundance (right axis) per joint size.*

# 4. Discussion

## 4.1. Results

### 4.1.1. Species

#### Species richness

In his survey (1984-1998) of the vegetation in all habitat types in the city of Zurich, Landolt (2000) reported 1210 native species and neophytes. Except for four species determined with uncertainty (*Elymus* cf. *caninus*, *Populus* cf. *balsamifera, Populus* cf. *balsamifera, Picea* cf. *glauca, Veronica* cf. *cymbalaria*), all species identified in the present study of wall vegetation are listed in the survey of Landolt and represent around 14 % of the species listed for Zurich. According to Landolt (2000), the distribution in Zurich in the period of his survey of the current study species was for most species widespread (63 %) or rather widespread (16 %), scattered for 7 %, rather seldom for 4 % and seldom for 8 % of the species. The four species not listed by Landolt (2000) represent 2 %. As long as their classification remains uncertain, they cannot be considered as new to Zurich. The remaining 1 % results from two species, *Epilobium collinum* and *Teucrium botrys*, which according to Landolt have no confirmed observations (*Epilobium collinum*) respectively no recent confirmed observation (*Teucrium botrys*). But according to the observation and distribution of species on the website of info flora (2021), *Epilobium collinum* has been observed in the area of Zurich after 1999 (confirmed observation). The observations of *Teucrium botrys* info flora, before and after the survey of Landolt, are all effectively not confirmed.

Comparing the species of the wall tops and vertical wall surface of the present study with the study of wall vegetation in Zurich of Guggenheim (1992), the number of species (respectively genera if species could not be determined) reported by Guggenheim is 199, whereas in the present study species richness is 128 with 48 species (35 %) being also on the list of Guggenheim.

Looking at the frequency of species on the walls (for comparison with other papers (only vertical wall surfaces are considered here) only 10 % of all species occurred on five or more walls and most species have been observed only on one wall (67 %). Guggenheim (1992) found in Zurich 51 % species on one wall only. In a study from New Zealand (de Neef et al., 2008), which comprehends also lichens, 23 % of all species were found on five or more walls in Christchurch (115 species, 70 walls) and in Dunedin 50 % of all species (70 species, 25 walls). The largest study on wall vegetation in south-eastern Essex with 650 walls (Payne, 1978) reports 43 % of total 286 species occurring in five or more walls and 30 % of the species in one wall only. Most probably, with higher number of investigated walls also a higher probability exists, that same species occur on more walls. Guggenheim (1992) concludes, that often species from the surrounding areas of the wall randomly colonize the walls. Further, Yalcinalp and Meral (2017) deduce that the quite large diversity in species may be due to several different factors such as geography, plant characteristics or history of cities.

The 4 $m^2$ plots of the vertical wall surfaces show an average species richness of 5, (Chen et al., 2020) in their study in Chongqing calculated on 3 $m^2$ an average species richness of 7.1, the higher average species richness could be explained with the humid-subtropical climate in this Chinese city.

**Neophytes**

Whereas Guggenheim identified on vertical wall surfaces and wall top 62 % of total 199 native species, 12 % archaeophytes and 22 % neophytes, our study reports more native species (75 %), less archaeophytes (5 %) and neophytes (20 %) for this two types of wall elements together (113 species). Looking only at the neophytes in the plot areas of the current study it resulted that abundance was substantial higher when maintenance was regular on wall top and wall base joint, whereas on vertical wall surface cover was similar for regular and seldom maintenance. No plausible explanation for this effect could be found. Nevertheless, in both studies overall native species are predominant, analogue to a study in the city of Trabzon (Turkey) (Yalcinalp & Meral, 2017) which reports 66 % of native species and one in Chongqing (China) (Chen et al., 2020) reporting 90 % native species. Contrarily, the study in New Zealand (de Neef et al., 2008) reports for two cities in average 9 % only of native species on urban walls. They estimate the reasons for the general decrease of native species in urban environments to be elimination of (native) seed sources, young age of walls, less jointed and rocky wall substrates and frequent cleaning and sterilizing. However, these issues are applicable in similar manner to Zurich too but do not have the same effect size on native species growing on walls. Perhaps the distance of city walls to original rocky habitat of native species and the large replacement of original vegetation by exotic vegetation (de Neef et al., 2008) play a role in this question respectively would explain the large difference.
In this study wall top showed the highest percentage of native species (88 %) and lowest of neophytes (6 %), followed by vertical wall surface (74 % native, 17 neophytes) and wall base joint (65 % native, 19 % neophytes). This indicates that harsher conditions on wall top (exposition to higher temperatures, less water resources, more wind) favor native species which seem to be better adapted to tolerate stress. A similar explanation could be given for the results issuing from vertical wall surfaces, although the conditions may be less harsh there (more moisture from the inside of the wall or the soil behind the retainment wall, slightly lower temperature in summer due to the different incident angle of sunlight). The wall base joint has more favorable conditions, with more soil (nutrients, moisture), and offers more protection against wind exposure. The figures for the wall base joint correspond to a certain degree to the average figures for the whole flora Zurich (flora inventory 1984-1998 of all habitat types in the municipality) (Landolt, 2000): 58 % native, 19 % archaeophytes and 23 % neophytes species of total 1211 species. Comparable results and conclusion are reported in the study of different habitats (semi-natural soils, paved areas, walls, rooftops, manholes) in the Italian city of Bologna (Salinitro et al., 2018).

**Factors influencing species richness on vertical wall surface relevés:**

Overall walls with western-southwestern aspect showed the lowest number of species and cover but statistical analysis does not confirm any significant impact of aspect on cover or species richness on vertical wall surfaces. The New Zealand study (de Neef et al., 2008) reports only in Christchurch higher abundance (20 species) when the aspect of the wall is south (our north) than the average abundance in all other aspects, which is 15 species (for Christchurch and Dunedin). The authors explain this by south-facing walls beeing more moist. If this differencies are significant has not been calculated. In another study in Turkey (Yalcinalp & Meral, 2017) the aspect also did not result to be significant. As the strongest and main winds in Zurich come from southwest the drying effect of winds could be an explanation for the lower figures on walls with this aspect but additional sampling would be required to confirm, as only two walls in the current work showed this aspect.
No significant influence on cover or species richness of the vertical wall surfaces resulted to have factors such as the main construction material, the type (freestanding wall, retaining wall, wall of building/civil construction) and the height and the length of the wall. Among these factors, only in the New Zealand study (de Neef et al., 2008) the construction material seemed to show a slight lower average abundace for concrete compared to granite and basalt (no indication if this is significant or not).

Positive significant on vegetation cover (not on species richness) resulted only the triple interaction between the factors height of the plot (distance from wall bottom to lower border of the rectangular plot), wall inclination and wall seldom maintenance. This could be explained by higher wall inclination offering more surface for rain wain flowing then in joints and substratum and seldom maintenance on higher levels of the walls (i.e. less cutting of plants on height) allowing development of more foliage / greater plants. The New Zealand paper (de Neef et al., 2008) reports that abundance is higher for vegetation on 0.3 - 2.0 m heigth as 0-0.3 m heigth.

No building with spontaneous vegetation on the vertical wall surface has been found in this survey, analogue to a research on wall vegetation in Eastern Part of Lower Saxony (Brandes, 1987). The main reasons may be regular maintenance, insufficient water resources and/or no adequate sprouting place in the building wall structure.

### 4.1.2. Characteristic of the sprouting point

**Surface position**

Wall tops and wall base joints had mainly horizontal surfaces and were seldom inclined (i.e. surface differed ≥ 10° from the horizontal), species richness and abundance were corresponding lower on vertical surfaces. Vertical wall surfaces were mainly vertical and only 15 % were inclined

(i.e. surface differed ≥ 10° from the vertical). The species richness on inclined walls was more than 1/3 of the species richness of vertical walls and the cover (in % of total survey area) was with 5.2 % even more than 1/2 of the cover on vertical surface. As expected, the inclination of these vertical wall surfaces, ranging from 10° to 50°, seems on the one hand to facilitate the root taking of more species on the walls and on the other hand, due to the slightly higher exposure to rainwater than with a pure vertical surface, to allow a more vigorous growing of plants. But this concurrence is disadvantageously for ferns specialized on walls which have almost not been found on inclined walls, confirming literature (Brandes, 2013).

### Angle of the surface

According to the characteristic of the wall elements, the sprouting point of the plants on wall top was mainly plane and for the plants growing in the wall base joint dihedral angle bottom. Vertical wall surfaces similar had most species growing on plane surface, but five species have been found on vertical dihedral angel top, right below the wall top cover plate of retainment walls. Due to the cover plate these plants are not at all exposed to rain. As most of those species require moist soil and rather shady conditions, the humidity must come from the soil behind the retainment wall and the cover plate seems to guarantee sufficient shade. The plants sprouting on the three freestanding walls on plane surface in contrast are completely depending on rainwater, this may explain why only relevés on the north, northeast or northwest side of the walls resulted. Vertical dihedral angles on walls are rather seldom, the two observations made on two different walls with the two surfaces forming the dihedral angle being of different material seem to be a similar sprouting point like joints on plane surfaces.

### Texture

Contrary to wall surfaces of strong or weak roughness, smooth texture of walls seems not to be appropriate for wall vegetation, probably because not sufficient dust and rotting material is accumulating on such surfaces and thus no adequate substrate is available for plants. Most plants were found on surfaces of week roughness as well some on surfaces of strong roughness. The differences in quantities are rather corresponding to the numeric different texture characteristic of the walls than to preferences of the species.

### Form of the sprouting point

Cracks as sprouting point have been observed seldom on the three different wall elements, most were on wall tops and vertical wall surfaces of small garden/retainment walls. They appeared mainly on plastered wall elements but also on wall elements made of sandstone or limestone. If cracks were present in the plot area usually plants were growing there. Joints were the most common sprouting point of plants and showed the highest species richness on all three wall elements. On wall top the abundance was although higher if sprouting point were pores, which was mainly due to mosses. Mosses on vertical wall surfaces were also predominant in relation to cover in

pores and in the top ten in joints, showing the highest cover over all other species. Pores with sprouting plants were observed on plastered vertical wall surfaces or vertical wall surfaces made of sandstone and on wall tops made of natural stone, granite, sandstone or limestone. *Asplenium ruta-muraria*, having the second highest cover over all species on the vertical wall surface, had the highest cover in joints and was furthermore as only species present on all three forms of sprouting point. Due to the construction characteristic of the wall base joint, the joints were the main sprouting form of plants there. But, in single cases, there were cracks in the horizontal surface forming the joint with plants growing. Overall, all forms of sprouting points were vegetated, the differences in species number populating them is mainly due to their different frequency on walls and different location on the wall (wall top, vertical wall surface, wall base joint) causing varying environmental conditions.

**Substratum**

Principal substratum on wall top and vertical wall surfaces is masonry as plants mainly sprouted in joints. Accordingly, species richness and abundance respectively cover was highest with substratum masonry. On wall top additional earth accumulated in cracks or joints and mosses growing in joints and pores were substratum for a good number of species resulting in a correspondent high abundance respectively cover. Loose filling material as substratum for plants was mainly found on vertical wall surfaces and there, only in joints of two natural stone walls. The summarized species richness and cover of these two walls was proportional higher compared to the corresponding figures of the other 31 vertical wall surfaces. The reasons could be that their not sealed joints offer more space for further species, that the humus content of the substratum is higher thus more nutrients are available, and that the substratum can retain more water after rainfall than masonry having joints sealed with mortar. Earth and moss as substratum on vertical wall surfaces occurred seldom and only in joints and their species richness and cover resulted correspondingly low. Wall base joints had mainly earth as substratum, seldom loose filling material. In summary, substratum type seems to be more relevant when water provision is limited like on wall top or vertical wall surface.

**Sun exposure**

For all three wall elements species richness and abundance respectively cover were lowest with sprouting point in shade. On wall tops predominant species were mosses, *Glechoma hederacea* subsp*. hederacea*, both present under sun, partial shade and shade, and *Hedera helix* with sprouting points in sun and partial shade. The other 25 species (90 %) occurred only under one level of sun exposure. On vertical wall surfaces and wall base joints 25 % of all species grew under more than one sun exposure level, possibly this figure is higher because for these two wall elements more relevés were done. On vertical wall surfaces species richness and cover was similar for species growing under sun and partial sun. However, on wall base 30 % more species grew under sun

as under partial sun having also 60 % higher abundance. This and the predominance of *Taraxacum officinale* aggr. on wall base joints indicates that this habitat is rich in nutriments and rather moist, compared to wall tops and vertical wall surfaces. On wall top, although species richness was slightly higher with sprouting points in sun than in partial shade, abundance of species growing in partial shade was twice the abundance of species growing in sun and three times the abundance of species in shade. High abundance on wall top seems to be favoured by partial shade. The four fern species (5 % of all species) have been mainly observed on vertical wall surfaces (only two other occurrences on wall tops). Their total cover was largest with sprouting point in sun and partial shade, but only two species (*Asplenium ruta-muraria*, *Phyllitis scolopendrium*) were found under sun whereas under partial sun and shade all four species were observed. Mosses showed the largest cover under partial shade (2.5 % of the total survey area) followed by ferns and other vascular plants (both around 1.7 % cover). With 4.8 % the largest cover was reached under sun by other vascular plants 4.8 %.

**Water exposure**

All sprouting points on wall tops were exposed to rain. On vertical wall surfaces and wall base joints most sprouting points of most species were also exposed to rain, only few were exposed to trickling water. In addition, on vertical wall surfaces of five retainment walls 10 species grew sheltered from rain and with no exposure to trickling water. Their species number is similar to the one of species growing exposed to trickling water, but their cover (0.2 % of the total survey area) is much smaller as the one of species exposed to trickling water (1.7 %). As some of the species prefer rather moist conditions, this also indicates that water provision must come from the soil behind the retainment walls.

### 4.1.3. Conclusions

In Zurich plants spontaneously colonize freestanding and retainment walls as well as walls of civil constructions. Walls of building usually are not colonized although some offer appropriate forms of sprouting points for vascular plants and mosses in form of joints between the bricks or sandstones and pores in concrete and plaster making up the facades. Main reason is certainly insufficient water provision / moisture due to roof overhang and according to Brandes (2013) also to building heating drying out the walls. Also, biocides respectively herbicides in concrete and facade plaster / colour prevent colonization of building walls.

The higher species richness in joints compared to cracks respectively pores is due certainly to their higher occurrence on walls than cracks respectively lower occurrence of pore-rich materials which are not treated with herbicides. Would the different sprouting points have similar frequency most probably the species richness would also be much higher for cracks and pores. Depending on form of sprouting point and occurrence on wall top, vertical wall surface or wall base joint predominance of species like mosses or ferns changes. This can be explained with different water and nutrient

provision, wind and sun exposure varying between these three wall elements and, as Brandes (2013) mentions, also with the restricted rooting space available on substratum and joints on wall top and vertical wall surfaces. Similarly, the higher frequency respectively abundance / cover of other predominant vascular plants on the three wall elements can be explained with species characteristics related to water, nutrients and light.

As long as sufficient water provision is guaranteed, all type of angles of surface can support vegetation. Higher sun exposure seems to influence positively species richness as sprouting points under sun and partial shade have almost equivalent high species richness on all three wall elements whereas lowest richness (and abundance) resulted when sprouting point was in shade. Abundance on the other hand is only influenced negatively with high sun exposure when water resources are strongly limited like on wall top, where abundance is highest under partial shade.

Species cover on vertical wall surfaces is significantly positively influenced by inclination in interaction with distance from the ground of the plot and seldom maintenance. This could be explained by higher wall inclination offering more surface for rain wain flowing then in joints and substratum and seldom maintenance on higher levels of the walls (i.e. less cutting of plants on height) allowing development of more foliage / greater plants.

Water provision is the most critical point for successful facade vegetation on buildings in terms of species richness and cover. Freestanding walls, which correspond best building walls in respect to water provision (only rain water), show spontaneous vegetation only on the north, northeast or northwest side of the walls in Zurich, same for the only freestanding wall assessed by Guggenheim (1992) in Zurich with north-eastern aspect. To realize similar water provision / moisture on facades as exist on retainment walls using only raining water, two different options can be considered:

1. **Inclination** As this study shows and is stated in literature (Brandes, 2013), inclination above 10° of vertical wall increases water availability for plants with higher cover. Thus, when planning terraced buildings in the hilly parts of Zurich, inclined facade walls could be considered.
2. **Integrate rainwater flow and water retainment in the facade elements** Literature review resulted in only one project realized so far incorporating directly in the facades sprouting places for plants (as well as nesting sites for different animal species). This Project, «École Primaire des Sciences et de la Biodiversité in Paris» (*Chartier Dalix*, 2021), has been realized 2014. The concrete blocks hosting the sprouting structures in form of fissures were not yet well vegetated in 2020 as pH value of concrete decreases only with the years becoming a more appropriate environment for plants (*L'école des Sciences et de la Biodiversité accroît encore son potentiel écologique*, 2020). The architect office Chartier Dalix, which developed the concrete wall elements together with ecologist consultants, are since 2017 working on a new concept of facade elements which incorporate interconnected

voids. (*Architecture and Biodiversity – Designing a new urban ecosystem*, 2021; Chayaamor-Heil & Vitalis, 2020). The idea of this interconnected voids is to offer more rooting space to plants, allow drippling down of water and, filled with adequate substrate, retain water. In the following years, testing of different materials for the facade elements and the substrate as well as mycorrhiza growth have been performed (*Architecture and Biodiversity – Designing a new urban ecosystem*, 2021). A dissertation project with the cooperation of architect office Chartier Dalix started in 2019 with the title «Theoretical, technical and biological study and definition of a biodiverse wall. A new biodiversity-based Vertical Greenery System.» (Lewandowski, 2019). It's expected that this thesis delivers new information on appropriate design of wall facades to support biodiversity in urban areas.

In Zurich walls with aspect in the main wind directions show lowest species richness and cover. Further research would be required to determine if there is a significant influence of wind on species richness / cover of walls.

### 4.2. Outlook

A wall offers with wall top, vertical wall surface and wall base different microhabitats. This and other study (Guggenheim, 1992; Yalcinalp & Meral, 2017) on up to 100 walls show, that frequency of species on different walls is not very high and most species occur only on single walls. Only one study with almost 600 walls, visited twice and on different seasons (Payne, 1978) reported a much higher species frequency and lower percentage of species assessed only once on a wall. It can be concluded that species diversity between the single walls is quite high and thus, if such spontaneous vegetation is facilitated to colonize numerous facades in cities offering steppingstones patches of habitats to seldom native species, the cities biodiversity and bioconservation is enhanced. Based on recorded species data in Zurich, it is supposed that neophyte species would not profit from such additional habitats on facades if the facades offer similar harsh environment conditions as vertical wall surfaces. Similar, for woody species the harsh conditions on wall prevent such species to reach adult stage (Arnet et al., 1995; Brandes, 2013) and regular cutting (every 1-2 years) of such species on facade would represent one of the few maintenance work required on spontaneously vegetated facades.

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# Appendixes

## Table of content

## Appendix 7 Various tables

*Table 15 Species richness and abundance per wall and mean per transect section.*

| wall ID | species richness | abundance | # transect sections | mean species richness | mean abundance |
|---|---|---|---|---|---|
| **13** | 3 | 21 | 7 | **2.00** | **3.00** |
| **20** | **6** | **24** | 8 | **2.00** | **3.00** |
| **30** | 4 | **24** | 8 | 1.63 | **3.00** |
| **12** | **6** | 17 | 8 | 1.50 | 2.13 |
| **17** | 2 | 10 | 5 | 1.00 | 2.00 |
| **44** | 3 | 12 | 8 | 0.63 | 1.50 |
| **18** | 4 | 5 | 8 | 0.63 | 0.63 |
| **22** | 3 | 5 | 8 | 0.50 | 0.63 |
| **29** | 3 | 4 | 8 | 0.50 | 0.50 |
| **46** | 4 | 4 | 8 | 0.50 | 0.50 |
| **8** | 2 | 3 | 8 | 0.38 | 0.38 |

*Table 16 Wall top: species and their abundance on horizontal and incllined surface position.*

| species per surface position | abundance |
|---|---|
| **horizontal** | **119** |
| Mosses | 30 |
| *Hedera helix* | 14 |
| *Geranium robertianum* | 12 |
| *Cerastium fontanum* | 9 |
| *Glechoma hederacea* subsp. *hederacea* | 9 |
| *Poa nemoralis* | 6 |
| *Taraxacum officinale* aggr. | 5 |
| *Hieracium murorum* aggr. | 5 |
| *Sedum spurium* | 4 |
| *Carex ornithopoda* | 3 |
| *Sedum album* | 3 |
| *Poa annua* | 2 |
| *Cynodon dactylon* | 2 |
| *Asplenium ruta-muraria* | 2 |
| *Hieracium* sp. | 1 |
| *Sedum* sp. | 1 |
| *Silene coronaria* | 1 |
| *Calystegia* sp. | 1 |
| *Agrostis stolonifera* | 1 |
| *Geum urbanum* | 1 |
| *Cotoneaster* sp. | 1 |
| *Dactylis glomerata* | 1 |
| *Linaria vulgaris* | 1 |
| *Fragaria vesca* | 1 |
| *Plantago lanceolata* | 1 |
| *Galium mollugo* | 1 |
| *Aquilegia vulgaris* | 1 |
| **inclined** | **10** |
| *Glechoma hederacea* subsp. *hederacea* | 9 |
| *Euphorbia peplus* | 1 |
| **total** | **129** |

*Table 17 Wall top: Species and their abundance per angle of the surface of the sprouting point.*

| species per angle of the surface | abundance |
|---|---|
| **horizontal dihedral angle bottom** | |
| *Asplenium ruta-muraria* | 2 |
| *Hedera helix* | 1 |
| **plane** | |
| *Agrostis stolonifera* | 1 |
| *Aquilegia vulgaris* | 1 |
| *Calystegia* sp. | 1 |
| *Carex ornithopoda* | 3 |
| *Cerastium fontanum* | 9 |
| *Cotoneaster* sp. | 1 |
| *Cynodon dactylon* | 2 |
| *Dactylis glomerata* | 1 |
| *Euphorbia peplus* | 1 |
| *Fragaria vesca* | 1 |
| *Galium mollugo* | 1 |
| *Geranium robertianum* | 12 |
| *Geum urbanum* | 1 |
| *Glechoma hederacea* subsp. *hederacea* | 18 |
| *Hedera helix* | 13 |
| *Hieracium murorum* aggr. | 5 |
| *Hieracium* sp. | 1 |
| *Linaria vulgaris* | 1 |
| Mosses | 30 |
| *Plantago lanceolata* | 1 |
| *Poa annua* | 2 |
| *Poa nemoralis* | 6 |
| *Sedum album* | 3 |
| *Sedum* sp. | 1 |
| *Sedum spurium* | 4 |
| *Silene coronaria* | 1 |
| *Taraxacum officinale* aggr. | 5 |
| **total** | **129** |

*Table 18 Wall top:: Species and their abundance per texture of the sprouting point.*

| species per texture type | abundance |
|---|---|
| **strong roughness** | **24** |
| *Cerastium fontanum* | 9 |
| Mosses | 8 |
| *Poa annua* | 2 |
| *Taraxacum officinale* aggr. | 5 |
| **weak roughness** | **105** |
| *Aquilegia vulgaris* | 1 |
| *Asplenium ruta-muraria* | 2 |
| *Calystegia* sp. | 1 |
| *Dactylis glomerata* | 1 |
| *Fragaria vesca* | 1 |
| *Galium mollugo* | 1 |
| *Geranium robertianum* | 12 |
| *Geum urbanum* | 1 |
| *Glechoma hederacea* subsp. *hederacea* | 18 |
| *Hedera helix* | 14 |
| *Hieracium murorum* aggr. | 5 |
| *Hieracium* sp. | 1 |
| Mosses | 22 |
| *Plantago lanceolata* | 1 |
| *Poa nemoralis* | 6 |

| species per texture type | abundance |
|---|---|
| *Sedum album* | 3 |
| *Sedum spurium* | 4 |
| *Agrostis stolonifera* | 1 |
| *Carex ornithopoda* | 3 |
| *Cotoneaster* sp. | 1 |
| *Cynodon dactylon* | 2 |
| *Euphorbia peplus* | 1 |
| *Linaria vulgaris* | 1 |
| *Sedum* sp. | 1 |
| *Silene coronaria* | 1 |
| **total** | **129** |

*Table 19 Wall top: Species and their abundance per form of sprouting point.*

| species per form of sprouting point | abundance |
|---|---|
| **crack** | **20** |
| *Glechoma hederacea* subsp. *hederacea* | 9 |
| *Poa nemoralis* | 6 |
| *Hieracium murorum* aggr. | 3 |
| *Sedum* sp. | 1 |
| *Euphorbia peplus* | 1 |
| **joint** | **54** |
| *Hedera helix* | 13 |
| Mosses | 6 |
| *Cerastium fontanum* | 6 |
| *Taraxacum officinale* aggr. | 5 |
| *Carex ornithopoda* | 3 |
| *Sedum spurium* | 2 |
| *Asplenium ruta-muraria* | 2 |
| *Glechoma hederacea* subsp. *hederacea* | 2 |
| *Hieracium murorum* aggr. | 2 |
| *Geum urbanum* | 1 |
| *Linaria vulgaris* | 1 |
| *Calystegia* sp. | 1 |
| *Aquilegia vulgaris* | 1 |
| *Dactylis glomerata* | 1 |
| *Hieracium* sp. | 1 |
| *Agrostis stolonifera* | 1 |
| *Fragaria vesca* | 1 |
| *Cotoneaster* sp. | 1 |
| *Plantago lanceolata* | 1 |
| *Silene coronaria* | 1 |
| *Sedum album* | 1 |
| *Galium mollugo* | 1 |
| **pore** | **55** |
| Mosses | 24 |
| *Geranium robertianum* | 12 |
| *Glechoma hederacea* subsp. *hederacea* | 7 |
| *Cerastium fontanum* | 3 |
| *Cynodon dactylon* | 2 |
| *Sedum spurium* | 2 |
| *Poa annua* | 2 |
| *Sedum album* | 2 |
| *Hedera helix* | 1 |
| **total** | **129** |

*Table 20 Wall top: species present on 3, 2 or only 1 forms of sprouting point.*

| form of sprouting point | crack | joint | pore | total |
|---|---|---|---|---|
| | | abundance | | |
| *Glechoma hederacea* subsp. *hederacea* | 9 | 2 | 7 | 18 |
| *Hieracium murorum* aggr. | 3 | 2 | | 5 |
| Mosses | | 6 | 24 | 30 |
| *Hedera helix* | | 13 | 1 | 14 |
| *Cerastium fontanum* | | 6 | 3 | 9 |
| *Sedum spurium* | | 2 | 2 | 4 |
| *Sedum album* | | 1 | 2 | 3 |
| *Euphorbia peplus* | 1 | | | 1 |
| *Sedum* sp. | 1 | | | 1 |
| *Poa nemoralis* | 6 | | | 6 |
| *Cotoneaster* sp. | | 1 | | 1 |
| *Galium mollugo* | | 1 | | 1 |
| *Geum urbanum* | | 1 | | 1 |
| *Agrostis stolonifera* | | 1 | | 1 |
| *Calystegia* sp. | | 1 | | 1 |
| *Asplenium ruta-muraria* | | 2 | | 2 |
| *Dactylis glomerata* | | 1 | | 1 |
| *Taraxacum officinale* aggr. | | 5 | | 5 |
| *Hieracium* sp. | | 1 | | 1 |
| *Carex ornithopoda* | | 3 | | 3 |
| *Aquilegia vulgaris* | | 1 | | 1 |
| *Plantago lanceolata* | | 1 | | 1 |
| *Linaria vulgaris* | | 1 | | 1 |
| *Silene coronaria* | | 1 | | 1 |
| *Fragaria vesca* | | 1 | | 1 |
| *Geranium robertianum* | | | 12 | 12 |
| *Cynodon dactylon* | | | 2 | 2 |
| *Poa annua* | | | 2 | 2 |
| **total** | **20** | **54** | **55** | **129** |

*Table 21 Wall top: Species and their abundance per type of substratum.*

| species per substratum type | abundance |
|---|---|
| **earth** | **30** |
| *Glechoma hederacea* subsp. *hederacea* | 8 |
| *Poa nemoralis* | 6 |
| *Hieracium murorum* aggr. | 5 |
| Mosses | 3 |
| *Sedum spurium* | 2 |
| *Cotoneaster* sp. | 1 |
| *Geum urbanum* | 1 |
| *Aquilegia vulgaris* | 1 |
| *Silene coronaria* | 1 |
| *Fragaria vesca* | 1 |
| *Sedum album* | 1 |
| **masonry** | **77** |
| Mosses | 27 |
| *Geranium robertianum* | 12 |
| *Glechoma hederacea* subsp. *hederacea* | 10 |
| *Hedera helix* | 6 |
| *Cerastium fontanum* | 6 |
| *Carex ornithopoda* | 3 |
| *Cynodon dactylon* | 2 |
| *Asplenium ruta-muraria* | 2 |
| *Linaria vulgaris* | 1 |
| *Dactylis glomerata* | 1 |

| species per substratum type | abundance |
|---|---|
| *Calystegia* sp. | 1 |
| *Plantago lanceolata* | 1 |
| *Euphorbia peplus* | 1 |
| *Taraxacum officinale* aggr. | 1 |
| *Sedum* sp. | 1 |
| *Agrostis stolonifera* | 1 |
| *Galium mollugo* | 1 |
| **moss** | **22** |
| *Hedera helix* | 8 |
| *Taraxacum officinale* aggr. | 4 |
| *Cerastium fontanum* | 3 |
| *Sedum spurium* | 2 |
| *Sedum album* | 2 |
| *Poa annua* | 2 |
| *Hieracium* sp. | 1 |
| **total** | **129** |

*Table 22 Wall top: species present on 2 or 1 substrata.*

| | earth | masonry | moss | total |
|---|---|---|---|---|
| **substratum** | | **abundance** | | |
| *Glechoma hederacea* subsp. *hederacea* | 8 | 10 | | 18 |
| Mosses | 3 | 27 | | 30 |
| *Sedum spurium* | 2 | | 2 | 4 |
| *Sedum album* | 1 | | 2 | 3 |
| *Hedera helix* | | 6 | 8 | 14 |
| *Cerastium fontanum* | | 6 | 3 | 9 |
| *Taraxacum officinale* aggr. | | 1 | 4 | 5 |
| *Poa nemoralis* | 6 | | | 6 |
| *Hieracium murorum* aggr. | 5 | | | 5 |
| *Aquilegia vulgaris* | 1 | | | 1 |
| *Cotoneaster* sp. | 1 | | | 1 |
| *Fragaria vesca* | 1 | | | 1 |
| *Geum urbanum* | 1 | | | 1 |
| *Silene coronaria* | 1 | | | 1 |
| *Geranium robertianum* | | 12 | | 12 |
| *Carex ornithopoda* | | 3 | | 3 |
| *Asplenium ruta-muraria* | | 2 | | 2 |
| *Cynodon dactylon* | | 2 | | 2 |
| *Agrostis stolonifera* | | 1 | | 1 |
| *Calystegia* sp. | | 1 | | 1 |
| *Dactylis glomerata* | | 1 | | 1 |
| *Euphorbia peplus* | | 1 | | 1 |
| *Galium mollugo* | | 1 | | 1 |
| *Linaria vulgaris* | | 1 | | 1 |
| *Plantago lanceolata* | | 1 | | 1 |
| *Sedum* sp. | | 1 | | 1 |
| *Poa annua* | | | 2 | 2 |
| *Hieracium* sp. | | | 1 | 1 |
| **total** | **30** | **77** | **22** | **129** |

*Table 23 Wall top: Species and their abundance per level of sun exposure.*

| species per sun exposure level | abundance |
|---|---|
| **sun** | **33** |
| *Glechoma hederacea* subsp. *hederacea* | 8 |
| Mosses | 7 |
| *Hedera helix* | 5 |

| species per sun exposure level | abundance |
|---|---|
| *Asplenium ruta-muraria* | 2 |
| *Galium mollugo* | 1 |
| *Calystegia* sp. | 1 |
| *Silene coronaria* | 1 |
| *Geum urbanum* | 1 |
| *Plantago lanceolata* | 1 |
| *Agrostis stolonifera* | 1 |
| *Linaria vulgaris* | 1 |
| *Sedum* sp. | 1 |
| *Aquilegia vulgaris* | 1 |
| *Dactylis glomerata* | 1 |
| *Hieracium* sp. | 1 |
| **partial shade** | **74** |
| Mosses | 22 |
| *Geranium robertianum* | 12 |
| *Hedera helix* | 9 |
| *Cerastium fontanum* | 9 |
| *Taraxacum officinale* aggr. | 5 |
| *Sedum spurium* | 4 |
| *Carex ornithopoda* | 3 |
| *Sedum album* | 3 |
| *Cynodon dactylon* | 2 |
| *Poa annua* | 2 |
| *Fragaria vesca* | 1 |
| *Glechoma hederacea* subsp. *hederacea* | 1 |
| *Cotoneaster* sp. | 1 |
| **shade** | **22** |
| *Glechoma hederacea* subsp. *hederacea* | 9 |
| *Poa nemoralis* | 6 |
| *Hieracium murorum* aggr. | 5 |
| *Euphorbia peplus* | 1 |
| Mosses | 1 |
| **total** | **129** |

*Table 24 Wall top: species growing under different levels of sun exposure.*

| species | sun | partial shade | shade | total |
|---|---|---|---|---|
| | abundance | | | |
| Mosses | 7 | 22 | 1 | 30 |
| *Glechoma hederacea* subsp. *hederacea* | 8 | 1 | 9 | 18 |
| *Hedera helix* | 5 | 9 | | 14 |
| *Asplenium ruta-muraria* | 2 | | | 2 |
| *Agrostis stolonifera* | 1 | | | 1 |
| *Aquilegia vulgaris* | 1 | | | 1 |
| *Calystegia* sp. | 1 | | | 1 |
| *Dactylis glomerata* | 1 | | | 1 |
| *Galium mollugo* | 1 | | | 1 |
| *Geum urbanum* | 1 | | | 1 |
| *Hieracium* sp. | 1 | | | 1 |
| *Linaria vulgaris* | 1 | | | 1 |
| *Plantago lanceolata* | 1 | | | 1 |
| *Sedum* sp. | 1 | | | 1 |
| *Silene coronaria* | 1 | | | 1 |
| *Geranium robertianum* | | 12 | | 12 |
| *Cerastium fontanum* | | 9 | | 9 |
| *Taraxacum officinale* aggr. | | 5 | | 5 |
| *Sedum spurium* | | 4 | | 4 |
| *Carex ornithopoda* | | 3 | | 3 |

| species | sun | partial shade | shade | total |
|---|---|---|---|---|
| | | abundance | | |
| *Sedum album* | | 3 | | 3 |
| *Cynodon dactylon* | | 2 | | 2 |
| *Poa annua* | | 2 | | 2 |
| *Cotoneaster* sp. | | 1 | | 1 |
| *Fragaria vesca* | | 1 | | 1 |
| *Poa nemoralis* | | | 6 | 6 |
| *Hieracium murorum* aggr. | | | 5 | 5 |
| *Euphorbia peplus* | | | 1 | 1 |
| **total** | **33** | **74** | **22** | **129** |

*Table 25 Vertical wall surface: species richness and cover per wall / plot*

| wall ID | species richness | cover [$m^2$] |
|---|---|---|
| **29** | **12** | 0.92 |
| **38** | **11** | 0.70 |
| **46** | 10 | 0.32 |
| **2** | 10 | **2.64** |
| **40** | 8 | 0.73 |
| **42** | 7 | 1.07 |
| **44** | 6 | 0.04 |
| **10** | 6 | 0.42 |
| **45** | 6 | 0.15 |
| **12** | 6 | 1.24 |
| **23** | 6 | 0.65 |
| **18** | 5 | 0.74 |
| **20** | 5 | 0.66 |
| **19** | 5 | 0.34 |
| **11** | 5 | **3.08** |
| **49** | 5 | 0.49 |
| **24** | 5 | 0.13 |
| **30** | 5 | 0.42 |
| **34** | 4 | 0.52 |
| **47** | 4 | 0.14 |
| **27** | 4 | 0.26 |
| **35** | 3 | 0.84 |
| **16** | 3 | 0.16 |
| **48** | 3 | 0.05 |
| **50** | 3 | 0.30 |
| **15** | 3 | 0.20 |
| **6** | 3 | 0.48 |
| **43** | 3 | 0.05 |
| **39** | 2 | 0.04 |
| **41** | 2 | 0.02 |
| **26** | 2 | 0.20 |
| **37** | 2 | 0.04 |
| **8** | 1 | 0.39 |
| **total** | | **18.46** |

*Table 26 Vertical wall surface: top ten species on vertical and inclined position.*

| species per surface position | cover [%] |
|---|---|
| **vertical** | **7.947** |
| *Asplenium ruta-muraria* | 2.781 |
| *Phyllitis scolopendrium* | 1.191 |
| *Hedera helix* | 0.889 |
| *Asplenium trichomanes* | 0.780 |
| Mosses | 0.684 |

| | |
|---|---|
| *Sedum rupestre* aggr. | 0.459 |
| *Dryopteris filix-mas* | 0.397 |
| *Taxus baccata* | 0.306 |
| *Calystegia* sp. | 0.306 |
| *Paulownia tomentosa* | 0.153 |
| **inclined** | **4.853** |
| Mosses | 2.510 |
| *Geranium robertianum* subsp. *robertianum* | 1.224 |
| *Hieracium lachenalii* | 0.214 |
| *Urtica dioica* | 0.153 |
| *Rubus fruticosus* aggr. | 0.153 |
| *Agrostis capillaris* | 0.153 |
| *Taraxacum officinale* aggr. | 0.141 |
| *Calystegia sepium* | 0.122 |
| *Cymbalaria muralis* | 0.092 |
| *Sonchus oleraceus* | 0.092 |
| **total** | **12.800** |

*Table 27 Vertical wall surface: top ten species present on vertical and inclined surfaces.*

| species | vertical | inclined | total |
|---|---|---|---|
| | | cover [%] | |
| Mosses | 0.684 | 2.510 | 3.194 |
| *Asplenium ruta-muraria* | 2.781 | 0.031 | 2.811 |
| *Taraxacum officinale* aggr. | 0.061 | 0.141 | 0.202 |
| *Calystegia sepium* | 0.046 | 0.122 | 0.168 |
| *Cymbalaria muralis* | 0.045 | 0.092 | 0.137 |
| *Sonchus oleraceus* | 0.018 | 0.092 | 0.110 |
| *Hieracium* sp. | 0.046 | 0.003 | 0.049 |
| *Mycelis muralis* | 0.017 | 0.031 | 0.047 |
| *Poa pratensis* aggr. | 0.000 | 0.015 | 0.016 |
| **total** | **3.698** | **3.036** | **6.734** |

*Table 28 Vertical wall surface: top ten species per angle of the surface of the sprouting point.*

| species per angle of the surface | cover [%] |
|---|---|
| **plane** | **10.950** |
| Mosses | 3.194 |
| *Asplenium ruta-muraria* | 2.323 |
| *Geranium robertianum* subsp. *robertianum* | 1.224 |
| *Phyllitis scolopendrium* | 1.086 |
| *Hedera helix* | 0.874 |
| *Asplenium trichomanes* | 0.780 |
| *Sedum rupestre* aggr. | 0.459 |
| *Dryopteris filix-mas* | 0.397 |
| *Calystegia* sp. | 0.306 |
| *Taxus baccata* | 0.306 |
| **horizontal dihedral angle top** | **0.535** |
| *Asplenium ruta-muraria* | 0.473 |
| *Calystegia sepium* | 0.031 |
| *Hedera helix* | 0.015 |
| *Convallaria majalis* | 0.010 |
| *Circaea lutetiana* | 0.006 |
| **vertical dihedral angle** | **0.150** |
| *Phyllitis scolopendrium* | 0.105 |
| *Taraxacum officinale* aggr. | 0.031 |
| *Asplenium ruta-muraria* | 0.015 |
| **total** | **11.636** |

*Table 29 Vertical wall surface: species present on two or three types of angle of the surface.*

| species | plane | horizontal dihedral angle top | vertical dihedral angle | total |
|---|---|---|---|---|
| | | cover [%] | | |
| *Asplenium ruta-muraria* | 2.323 | 0.473 | 0.015 | 2.811 |
| *Calystegia sepium* | 0.138 | 0.031 | | 0.168 |
| *Hedera helix* | 0.874 | 0.015 | | 0.889 |
| *Phyllitis scolopendrium* | 1.086 | | 0.105 | 1.191 |
| *Taraxacum officinale* aggr. | 0.171 | | 0.031 | 0.202 |
| **total** | **4.593** | **0.519** | **0.150** | **5.262** |

*Table 30 Vertical wall surface: top ten species per texture of the sprouting point.*

| top ten species per texture | cover [%] |
|---|---|
| **weak roughness** | **7.797** |
| *Asplenium ruta-muraria* | 2.441 |
| *Geranium robertianum* subsp. *robertianum* | 1.224 |
| *Hedera helix* | 0.813 |
| *Asplenium trichomanes* | 0.750 |
| Mosses | 0.684 |
| *Sedum rupestre* aggr. | 0.459 |
| *Phyllitis scolopendrium* | 0.426 |
| *Dryopteris filix-mas* | 0.388 |
| *Taxus baccata* | 0.306 |
| *Calystegia* sp. | 0.306 |
| **strong roughness** | **4.040** |
| Mosses | 2.510 |
| *Phyllitis scolopendrium* | 0.765 |
| *Asplenium ruta-muraria* | 0.370 |
| *Agrostis capillaris* | 0.153 |
| *Hedera helix* | 0.076 |
| *Hieracium* sp. | 0.031 |
| *Galium mollugo* | 0.031 |
| *Asplenium trichomanes* | 0.031 |
| *Taraxacum officinale* aggr. | 0.028 |
| *Corydalis lutea* | 0.015 |
| *Epilobium* sp. | 0.015 |
| *Erigeron annuus* | 0.015 |
| **total** | **11.837** |

*Table 31 Vertical wall surface: species present on both types of texture.*

| species | weak roughness | strong roughness | total |
|---|---|---|---|
| | cover [%] | | |
| *Asplenium ruta-muraria* | 2.441 | 0.370 | 2.811 |
| *Asplenium trichomanes* | 0.750 | 0.031 | 0.780 |
| *Corydalis lutea* | 0.092 | 0.015 | 0.107 |
| *Dryopteris filix-mas* | 0.388 | 0.009 | 0.397 |
| *Fragaria vesca* | 0.003 | 0.006 | 0.009 |
| *Galium mollugo* | 0.031 | 0.031 | 0.061 |
| *Glechoma hederacea* subsp. *hederacea* | 0.003 | 0.001 | 0.004 |
| *Hedera helix* | 0.813 | 0.076 | 0.889 |
| *Hieracium* sp. | 0.018 | 0.031 | 0.049 |
| Mosses | 0.684 | 2.510 | 3.194 |
| *Phyllitis scolopendrium* | 0.426 | 0.765 | 1.191 |
| *Poa pratensis* aggr. | 0.015 | 0.000 | 0.016 |
| *Taraxacum officinale* aggr. | 0.174 | 0.028 | 0.202 |
| **total** | **5.838** | **3.872** | **9.711** |

*Table 32 Vertical wall surface: top ten species per form of sprouting point.*

| top ten species per form of sprouting point | cover [%] |
|---|---|
| **joint** | **9.177** |
| *Asplenium ruta-muraria* | 2.725 |
| *Geranium robertianum* subsp. *robertianum* | 1.224 |
| *Phyllitis scolopendrium* | 1.191 |
| Mosses | 0.898 |
| *Hedera helix* | 0.889 |
| *Asplenium trichomanes* | 0.780 |
| *Sedum rupestre* aggr. | 0.459 |
| *Dryopteris filix-mas* | 0.397 |
| *Taxus baccata* | 0.306 |
| *Calystegia* sp. | 0.306 |
| **pore** | **2.369** |
| Mosses | 2.295 |
| *Bromus sterilis* | 0.028 |
| *Asplenium ruta-muraria* | 0.022 |
| *Geum urbanum* | 0.012 |
| *Lolium multiflorum* | 0.009 |
| *Primula acaulis* | 0.002 |
| *Cardamine hirsuta* | 0.001 |
| *Trisetum flavescens* | 0.000 |
| **crack** | **0.312** |
| *Agrostis capillaris* | 0.153 |
| *Asplenium ruta-muraria* | 0.064 |
| *Galium mollugo* | 0.031 |
| *Erigeron annuus* | 0.015 |
| *Lycopus europaeus* | 0.015 |
| *Epilobium* sp. | 0.015 |
| *Corydalis lutea* | 0.015 |
| *Ajuga reptans* | 0.003 |
| **total** | **11.858** |

*Table 33 Vertical wall surface: species present on two or three types of form of sprouting point.*

| | crack | joint | pore | total |
|---|---|---|---|---|
| species | | cover [%] | | |
| Mosses | | 0.898 | 2.295 | 3.194 |
| *Asplenium ruta-muraria* | 0.064 | 2.725 | 0.022 | 2.811 |
| *Corydalis lutea* | 0.015 | 0.092 | | 0.107 |
| *Galium mollugo* | 0.031 | 0.031 | | 0.061 |
| *Geum urbanum* | | 0.021 | 0.012 | 0.034 |
| *Primula acaulis* | | 0.024 | 0.002 | 0.026 |
| **total** | **0.110** | **3.792** | **2.331** | **6.233** |

*Table 34 Vertical wall surface: top ten species per substratum type.*

| top ten species per substratum | cover [%] |
|---|---|
| **earth** | **0.615** |
| *Asplenium ruta-muraria* | 0.612 |
| *Hieracium murorum* aggr. | 0.003 |
| *Poa pratensis* aggr. | 0.000 |
| **loose filling material** | **2.862** |
| *Asplenium ruta-muraria* | 0.122 |
| *Calystegia sepium* | 0.122 |
| *Calystegia* sp. | 0.306 |
| cf. *Elymus caninus* | 0.061 |
| *Clematis vitalba* | 0.061 |
| *Cymbalaria muralis* | 0.092 |

| top ten species per substratum | cover [%] |
|---|---|
| *Geranium robertianum* subsp. *robertianum* | 1.224 |
| *Rubus fruticosus* aggr. | 0.153 |
| *Sedum rupestre* aggr. | 0.459 |
| *Sonchus oleraceus* | *0.*107 |
| *Urtica dioica* | 0.153 |
| **masonry** | **9.525** |
| *Agrostis capillaris* | 0.153 |
| *Asplenium ruta-muraria* | 2.077 |
| *Asplenium trichomanes* | 0.780 |
| *Dryopteris filix-mas* | 0.397 |
| *Hedera helix* | 0.889 |
| *Hieracium lachenalii* | 0.214 |
| Mosses | 3.194 |
| *Paulownia tomentosa* | 0.153 |
| *Phyllitis scolopendrium* | 1.191 |
| *Taraxacum officinale* aggr. | 0.171 |
| *Taxus baccata* | 0.306 |
| **moss** | **0.040** |
| *Betula pendula* | 0.005 |
| *Buddleja davidii* | 0.031 |
| *Cerastium fontanum* | 0.002 |
| *Sagina procumbens* | 0.003 |
| **total** | **13.042** |

*Table 35 Vertical wall surface: species with germination on more than one substrata.*

| | earth | loose filling material | masonry | moss | total |
|---|---|---|---|---|---|
| ***species*** | | **cover [%]** | | | |
| *Asplenium ruta-muraria* | 0.612 | 0.122 | 2.077 | 0 | 2.811 |
| *Mycelis muralis* | 0.000 | 0.031 | 0.017 | 0 | 0.047 |
| *Sonchus oleraceus* | 0.000 | 0.107 | 0.003 | 0 | 0.110 |
| *Poa pratensis* aggr. | 0.000 | 0.000 | 0.015 | 0 | 0.016 |
| *Cymbalaria muralis* | 0.000 | 0.092 | 0.045 | 0 | 0.137 |
| *Calystegia sepium* | 0.000 | 0.122 | 0.046 | 0 | 0.168 |
| *Taraxacum officinale* aggr. | 0.000 | 0.031 | 0.171 | 0 | 0.202 |
| *Glechoma hederacea* | 0.000 | 0.015 | 0.003 | 0 | 0.018 |
| **total** | **0.612** | **0.520** | **2.377** | **0** | **3.510** |

*Table 36 Vertical wall surface: top ten species per sun exposure level.*

| top ten species per sun exposure level | cover [%] |
|---|---|
| **partial shade** | **5.682** |
| Mosses | 2.580 |
| *Asplenium ruta-muraria* | 1.072 |
| *Asplenium trichomanes* | 0.612 |
| *Hedera helix* | 0.476 |
| *Phyllitis scolopendrium* | 0.321 |
| *Hieracium lachenalii* | 0.214 |
| *Agrostis capillaris* | 0.153 |
| *Taraxacum officinale* aggr. | 0.113 |
| *Aquilegia vulgaris* | 0.077 |
| *Sedum spurium* | 0.064 |
| **shade** | **1.187** |
| *Dryopteris filix-mas* | 0.357 |
| *Asplenium trichomanes* | 0.168 |
| *Asplenium ruta-muraria* | 0.153 |
| Mosses | 0.139 |
| *Phyllitis scolopendrium* | 0.105 |

| top ten species per sun exposure level | cover [%] |
|---|---|
| *Corydalis lutea* | 0.092 |
| *Hedera helix* | 0.077 |
| *Cymbalaria muralis* | 0.042 |
| *Taraxacum officinale* aggr. | 0.034 |
| *Meconopsis cambrica* | 0.021 |
| **sun** | **6.070** |
| *Asplenium ruta-muraria* | 1.587 |
| *Geranium robertianum* subsp. *roberti-anum* | 1.224 |
| *Phyllitis scolopendrium* | 0.765 |
| Mosses | 0.475 |
| *Sedum rupestre* aggr. | 0.459 |
| *Hedera helix* | 0.336 |
| *Calystegia* sp. | 0.306 |
| *Taxus baccata* | 0.306 |
| *Paulownia tomentosa* | 0.153 |
| *Urtica dioica* | 0.153 |
| *Rubus fruticosus* aggr. | 0.153 |
| *Calystegia sepium* | 0.153 |
| **total** | **12.940** |

*Table 37 Vertical wall surface: species with sprouting point in more than one sun exposure level.*

| species | partial shade | shade | sun | total |
|---|---|---|---|---|
| | cover [%] | | | |
| Mosses | 2.580 | 0.139 | 0.475 | 3.194 |
| *Asplenium ruta-muraria* | 1.072 | 0.153 | 1.587 | 2.811 |
| *Phyllitis scolopendrium* | 0.321 | 0.105 | 0.765 | 1.191 |
| *Hedera helix* | 0.476 | 0.077 | 0.336 | 0.889 |
| *Asplenium trichomanes* | 0.612 | 0.168 | | 0.780 |
| *Dryopteris filix-mas* | 0.040 | 0.357 | | 0.397 |
| *Taraxacum officinale* aggr. | 0.113 | 0.034 | 0.055 | 0.202 |
| *Calystegia sepium* | 0.015 | | 0.153 | 0.168 |
| *Cymbalaria muralis* | | 0.042 | 0.095 | 0.137 |
| *Corydalis lutea* | | 0.092 | 0.015 | 0.107 |
| *Hieracium* sp. | 0.034 | | 0.015 | 0.049 |
| *Mycelis muralis* | | 0.002 | 0.046 | 0.047 |
| *Geum urbanum* | 0.021 | | 0.012 | 0.034 |
| *Primula acaulis* | 0.006 | 0.003 | 0.017 | 0.026 |
| *Glechoma hederacea* | 0.003 | | 0.015 | 0.018 |
| *Poa pratensis* aggr. | 0.015 | 0.000 | | 0.016 |
| *Fragaria vesca* | 0.003 | | 0.006 | 0.009 |
| *Glechoma hederacea* subsp. *hederacea* | 0.003 | | 0.001 | 0.004 |
| *Poa nemoralis* | 0.003 | 0.000 | | 0.003 |
| **total** | **5.318** | **1.172** | **3.594** | **10.084** |

*Table 38 Vertical wall surface: top ten species per water exposure type.*

| top ten species per water exposure level | cover |
|---|---|
| **exposed to rain** | **10.268** |
| Mosses | 3.089 |
| *Asplenium ruta-muraria* | 2.156 |
| *Geranium robertianum* subsp. *robertianum* | 1.224 |
| *Phyllitis scolopendrium* | 1.086 |
| *Hedera helix* | 0.874 |
| *Asplenium trichomanes* | 0.765 |
| *Dryopteris filix-mas* | 0.355 |
| *Taxus baccata* | 0.306 |

| top ten species per water exposure level | cover |
|---|---|
| *Hieracium lachenalii* | 0.214 |
| *Taraxacum officinale* aggr. | 0.199 |
| **exposed to trickling water** | **1.652** |
| *Asplenium ruta-muraria* | 0.527 |
| *Sedum rupestre* aggr. | 0.459 |
| *Calystegia* sp. | 0.306 |
| Mosses | 0.105 |
| *Phyllitis scolopendrium* | 0.105 |
| *Cymbalaria muralis* | 0.042 |
| *Dryopteris filix-mas* | 0.042 |
| *Chelidonium majus* | 0.031 |
| *Meconopsis cambrica* | 0.021 |
| *Hedera helix* | 0.016 |
| **covered** | **0.218** |
| *Asplenium ruta-muraria* | 0.129 |
| *Calystegia sepium* | 0.031 |
| *Mycelis muralis* | 0.017 |
| *Asplenium trichomanes* | 0.015 |
| *Convallaria majalis* | 0.010 |
| *Corylus avellana* | 0.009 |
| *Taraxacum officinale* aggr. | 0.003 |
| *Hieracium murorum* aggr. | 0.003 |
| *Poa nemoralis* | 0.000 |
| Mosses | 0.000 |
| **total** | **12.138** |

*Table 39 Vertical wall surface: species with sprouting point in more than one water exposure level.*

| species | exposed to rain | exposed to trickling water | covered | total |
|---|---|---|---|---|
| | | cover [%] | | |
| Mosses | 3.089 | 0.105 | 0.000 | 3.194 |
| *Asplenium ruta-muraria* | 2.156 | 0.527 | 0.129 | 2.811 |
| *Phyllitis scolopendrium* | 1.086 | 0.105 | | 1.191 |
| *Hedera helix* | 0.874 | 0.016 | | 0.889 |
| *Dryopteris filix-mas* | 0.355 | 0.042 | | 0.397 |
| *Cymbalaria muralis* | 0.095 | 0.042 | | 0.137 |
| *Sonchus oleraceus* | 0.095 | 0.015 | | 0.110 |
| *Primula acaulis* | 0.011 | 0.015 | | 0.026 |
| *Glechoma hederacea* | 0.003 | 0.015 | | 0.018 |
| *Asplenium trichomanes* | 0.765 | | 0.015 | 0.780 |
| *Taraxacum officinale* aggr. | 0.199 | | 0.003 | 0.202 |
| *Calystegia sepium* | 0.138 | | 0.031 | 0.168 |
| *Mycelis muralis* | 0.031 | | 0.017 | 0.047 |
| *Poa nemoralis* | 0.003 | | 0.000 | 0.003 |
| **total** | **8.899** | **0.881** | **0.195** | **9.976** |

*Table 40 Species with sprouting point covered from rain*

| species | cover [%] |
|---|---|
| Mosses | 0.000 |
| *Asplenium trichomanes* | 0.015 |
| *Asplenium ruta-muraria* | 0.129 |
| *Calystegia sepium* | 0.031 |
| *Convallaria majalis* | 0.010 |
| *Corylus avellana* | 0.009 |
| *Hieracium murorum* aggr. | 0.003 |
| *Mycelis muralis* | 0.017 |
| *Poa nemoralis* | 0.000 |

| species | cover [%] |
|---|---|
| *Taraxacum officinale* aggr. | 0.003 |
| **total** | **0.218** |

*Table 41 Vertical wall surface: top five species and top five families per aspect.*

| aspect | species | cover [m²] | families | cover [m²] |
|---|---|---|---|---|
| **north (4 walls)** | | | | |
| | *Dryopteris filix-mas* | 0.40 | Aspleniaceae | 0.41 |
| | *Asplenium ruta-muraria* | 0.21 | Dryopteridaceae | 0.40 |
| | *Asplenium trichomanes* | 0.20 | Mosses | 0.16 |
| | Mosses | 0.16 | Papaveraceae | 0.12 |
| | *Corydalis lutea* | 0.12 | Araliaceae | 0.10 |
| **northeast (8 walls)** | | | | |
| | *Asplenium ruta-muraria* | 0.94 | Aspleniaceae | 2.16 |
| | *Asplenium trichomanes* | 0.82 | Mosses | 0.26 |
| | *Phyllitis scolopendrium* | 0.40 | Araliaceae | 0.22 |
| | Mosses | 0.25 | Asteraceae | 0.12 |
| | *Hedera helix* | 0.22 | Convolvulaceae | 0.06 |
| **east (3 walls)** | | | | |
| | *Asplenium ruta-muraria* | 0.56 | Aspleniaceae | 0.56 |
| | *Hedera helix* | 0.40 | Asteraceae | 0.40 |
| | *Hieracium lachenalii* | 0.28 | Araliaceae | 0.40 |
| | Mosses | 0.20 | Mosses | 0.20 |
| | *Taraxacum officinale* aggr. | 0.12 | Crassulaceae | 0.10 |
| **southeast (6 walls)** | | | | |
| | *Asplenium ruta-muraria* | 0.51 | Aspleniaceae | 0.53 |
| | *Taxus baccata* | 0.40 | Taxaceae | 0.40 |
| | *Hedera helix* | 0.40 | Araliaceae | 0.40 |
| | *Paulownia tomentosa* | 0.20 | Paulowniaceae | 0.20 |
| | Mosses | 0.12 | Mosses | 0.12 |
| **south (4 walls)** | | | | |
| | *Geranium robertianum* subsp. *robertianum* | 1.60 | Geraniaceae | 1.60 |
| | *Sedum rupestre* aggr. | 0.60 | Crassulaceae | 0.60 |
| | *Asplenium ruta-muraria* | 0.47 | Convolvulaceae | 0.56 |
| | *Calystegia* sp. | 0.40 | Aspleniaceae | 0.47 |
| | *Urtica dioica* | 0.20 | Asteraceae | 0.24 |
| | *Rubus fruticosus* aggr. | 0.20 | | |
| **southwest (2 walls)** | | | | |
| | *Asplenium ruta-muraria* | 0.14 | Aspleniaceae | 0.14 |
| | *Corydalis lutea* | 0.02 | Papaveraceae | 0.02 |
| | *Primula acaulis* | 0.02 | Primulaceae | 0.02 |
| | *Hedera helix* | 0.02 | Araliaceae | 0.02 |
| **west (3 walls)** | | | | |
| | Mosses | 2.94 | Mosses | 2.94 |
| | *Phyllitis scolopendrium* | 1.14 | Aspleniaceae | 1.18 |
| | *Agrostis capillaris* | 0.20 | Poaceae | 0.20 |
| | *Cymbalaria muralis* | 0.05 | Plantaginaceae | 0.05 |
| | *Dryopteris filix-mas* | 0.05 | Dryopteridaceae | 0.05 |
| **northwest (3 walls)** | | | | |
| | *Asplenium ruta-muraria* | 0.80 | Aspleniaceae | 0.80 |
| | Mosses | 0.48 | Mosses | 0.48 |
| | *Lotus corniculatus* | 0.04 | Fabaceae | 0.04 |
| | *Dryopteris filix-mas* | 0.03 | Dryopteridaceae | 0.03 |
| | *Campanula portenschlagiana* | 0.01 | Campanulaceae | 0.01 |

*Table 42 Species richness and abundance per wall and plot and mean per transect section (transect section with vegetation).*

| wall ID | plot ID | species richness | total abundance | # transect sections | mean species richness per transect section | mean abundance per transect section |
|---|---|---|---|---|---|---|
| **23** | **37** | 11 | **102** | 8 | 3.13 | **12.75** |
| **22** | **35** | **16** | 95 | 8 | 4.88 | 11.88 |
| **33** | **53** | **16** | 93 | 8 | 4.63 | 11.63 |
| **3** | **4** | 9 | 80 | 7 | 2.86 | 11.43 |
| **1** | **1** | 6 | 9 | 1 | **6.00** | 9.00 |
| **7** | **8** | 8 | 36 | 4 | 3.75 | 9.00 |
| **36** | **56** | 4 | 72 | 8 | 1.75 | 9.00 |
| **9** | **12** | 11 | 50 | 6 | 3.17 | 8.33 |
| **28** | **43** | 15 | 49 | 8 | 3.25 | 6.13 |
| **2** | **3** | 11 | 37 | 8 | 2.50 | 4.63 |
| **21** | **33** | 8 | 37 | 8 | 1.88 | 4.63 |
| **20** | **32** | 14 | 35 | 8 | 2.38 | 4.38 |
| **48** | **73** | 12 | 34 | 8 | 2.88 | 4.25 |
| **29** | **46** | 5 | 33 | 8 | 2.13 | 4.13 |
| **25** | **40** | 5 | 33 | 8 | 2.00 | 4.13 |
| **14** | **21** | 4 | 32 | 8 | 1.38 | 4.00 |
| **31** | **50** | 6 | 22 | 6 | 2.00 | 3.67 |
| **10** | **14** | 3 | 9 | 3 | 1.33 | 3.00 |
| **12** | **18** | 6 | 23 | 8 | 2.13 | 2.88 |
| **8** | **11** | 7 | 23 | 8 | 1.38 | 2.88 |
| **30** | **49** | 3 | 22 | 8 | 1.75 | 2.75 |
| **13** | **20** | 9 | 19 | 7 | 2.57 | 2.71 |
| **32** | **51** | 7 | 19 | 7 | 1.00 | 2.71 |
| **24** | **39** | 7 | 21 | 8 | 1.50 | 2.63 |
| **18** | **28** | 9 | 15 | 8 | 1.38 | 1.88 |
| **5** | **6** | 5 | 9 | 7 | 0.86 | 1.29 |
| **39** | **60** | 6 | 10 | 8 | 1.38 | 1.25 |
| **44** | **67** | 5 | 9 | 8 | 0.63 | 1.13 |
| **4** | **5** | 3 | 3 | 3 | 1.00 | 1.00 |
| **15** | **23** | 3 | 5 | 7 | 0.86 | 0.71 |
| **32** | **52** | 3 | 4 | 7 | 0.43 | 0.57 |

*Table 43 Wall base joint: top ten species on horizontal or inclined surface.*

| top ten species per surface position | abundance |
|---|---|
| **horizontal** | **566** |
| *Taraxacum officinale* aggr. | 239 |
| *Setaria viridis* | 39 |
| *Geum urbanum* | 34 |
| *Sonchus oleraceus* | 34 |
| *Carex* sp. | 32 |
| *Poa annua* | 32 |
| Mosses | 31 |
| *Taraxacum* sp. | 28 |
| *Oxalis corniculata* | 25 |
| *Senecio vulgaris* | 24 |
| *Geranium robertianum* | 24 |
| *Cynodon dactylon* | 24 |
| **inclined** | **28** |
| Mosses | 6 |
| *Taraxacum officinale* aggr. | 4 |
| *Poa annua* | 3 |
| *Mycelis muralis* | 3 |
| *Hieracium murorum* aggr. | 2 |
| *Lamium galeobdolon* subsp. *galeobdolon* | 2 |
| *Geranium robertianum* | 2 |

| top ten species per surface position | abundance |
|---|---|
| cf. *Saxifraga aizoides* | 1 |
| *Glechoma hederacea* cf. subsp. *hirsuta* | 1 |
| *Glechoma hederacea* | 1 |
| *Picea* cf. *glauca* | 1 |
| *Carpinus betulus* | 1 |
| *Hypochaeris* cf. *radicata* | 1 |
| **total** | **594** |

*Table 44 Wall base joint: species present on both horizontal and inclined surfaces.*

| species | horizontal | inclined | total |
|---|---|---|---|
| | abundance | | |
| *Taraxacum officinale* aggr. | 239 | 4 | 243 |
| Mosses | 31 | 6 | 37 |
| *Poa annua* | 32 | 3 | 35 |
| *Geranium robertianum* | 24 | 2 | 26 |
| *Glechoma hederacea* | 3 | 1 | 4 |
| *Carpinus betulus* | 1 | 1 | 2 |
| **total** | **330** | **17** | **347** |

*Table 45 Wall base joint: top ten species abundance per texture of the sprouting point.*

| top ten species per texture type | abundance |
|---|---|
| **strong roughness** | **68** |
| *Taraxacum officinale* aggr. | 12 |
| *Viola odorata* | 11 |
| *Cynodon dactylon* | 11 |
| *Carex* sp. | 6 |
| Mosses | 5 |
| *Oxalis corniculata* | 5 |
| *Poa annua* | 4 |
| *Senecio vulgaris* | 3 |
| *Philadelphus coronarius* | 3 |
| *Geum urbanum* | 2 |
| *Geranium robertianum* | 2 |
| *Caltha palustris* | 2 |
| *Sambucus nigra* | 2 |
| **weak roughness** | **499** |
| *Taraxacum officinale* aggr. | 231 |
| *Setaria viridis* | 39 |
| *Sonchus oleraceus* | 33 |
| *Geum urbanum* | 32 |
| Mosses | 32 |
| *Poa annua* | 31 |
| *Taraxacum* sp. | 28 |
| *Carex* sp. | 26 |
| *Geranium robertianum* | 24 |
| *Cymbalaria muralis* | 23 |
| **total** | **567** |

*Table 46 Wall base joint: species growing on both type ot texture and their abundance.*

| species | strong roughness | weak roughness | total |
|---|---|---|---|
| | abundance | | |
| *Taraxacum officinale* aggr. | 12 | 231 | 243 |
| Mosses | 5 | 32 | 37 |
| *Poa annua* | 4 | 31 | 35 |
| *Sonchus oleraceus* | 1 | 33 | 34 |

| species | strong roughness | weak roughness | total |
|---|---|---|---|
| | abundance | | |
| *Geum urbanum* | 2 | 32 | 34 |
| *Carex* sp. | 6 | 26 | 32 |
| *Geranium robertianum* | 2 | 24 | 26 |
| *Oxalis corniculata* | 5 | 20 | 25 |
| *Cynodon dactylon* | 11 | 13 | 24 |
| *Senecio vulgaris* | 3 | 21 | 24 |
| *Origanum vulgare* | 1 | 12 | 13 |
| *Daucus carota* | 1 | 7 | 8 |
| *Poa pratensis* aggr. | 1 | 4 | 5 |
| *Rosa* sp. | 1 | 4 | 5 |
| *Sedum spurium* | 1 | 2 | 3 |
| *Polygonum aviculare* | 1 | 1 | 2 |
| *Carpinus betulus* | 1 | 1 | 2 |
| **total** | **58** | **494** | **552** |

*Table 47 Wall base joint: top ten species per form of sprouting point.*

| top ten species per form of sprouting point | abundance |
|---|---|
| **crack** | **5** |
| *Lamium galeobdolon* subsp. *galeobdolon* | 2 |
| *Carpinus betulus* | 1 |
| *Taraxacum officinale* aggr. | 1 |
| *Polygonum aviculare* | 1 |
| **joint** | **532** |
| *Taraxacum officinale* aggr. | 242 |
| *Setaria viridis* | 39 |
| Mosses | 37 |
| *Poa annua* | 35 |
| *Sonchus oleraceus* | 34 |
| *Geum urbanum* | 34 |
| *Carex* sp. | 32 |
| *Taraxacum* sp. | 28 |
| *Geranium robertianum* | 26 |
| *Oxalis corniculata* | 25 |
| **total** | **537** |

*Table 48 Wall base joint: species on both type of form of sprouting point.*

| species | crack | joint | total |
|---|---|---|---|
| | abundance | | |
| *Carpinus betulus* | 1 | 1 | 2 |
| *Taraxacum officinale* aggr. | 1 | 242 | 243 |
| *Polygonum aviculare* | 1 | 1 | 2 |
| **Grand Total** | **3** | **244** | **247** |

*Table 49 Wall base joint: top ten species per substratum.*

| top ten species per substratum type | abundance |
|---|---|
| **earth** | **320** |
| *Taraxacum officinale* aggr. | 101 |
| *Setaria viridis* | 39 |
| *Taraxacum* sp. | 28 |
| *Poa annua* | 26 |
| *Geranium robertianum* | 24 |
| *Sonchus oleraceus* | 23 |
| *Cynodon dactylon* | 21 |
| *Geum urbanum* | 20 |

| top ten species per substratum type | abundance |
|---|---|
| *Senecio vulgaris* | 20 |
| *Polygonum mite* | 18 |
| **loose filling material** | **23** |
| *Sedum rupestre* aggr. | 7 |
| *Plantago lanceolata* | 7 |
| *Cynodon dactylon* | 3 |
| *Geum urbanum* | 3 |
| *Chelidonium majus* | 2 |
| *Rumex acetosa* | 1 |
| **substratum not visible** | **319** |
| *Taraxacum officinale* aggr. | 142 |
| *Carex* sp. | 26 |
| Mosses | 23 |
| *Cymbalaria muralis* | 20 |
| *Sisymbrium officinale* | 19 |
| *Oxalis corniculata* | 16 |
| *Cotoneaster* sp. | 14 |
| *Sagina procumbens* | 14 |
| *Origanum vulgare* | 12 |
| *Sonchus oleraceus* | 11 |
| *Geum urbanum* | 11 |
| *Lapsana communis* | 11 |
| **total** | **662** |

*Table 50 Wall base joint: species on both substrata.*

| specie | earth | loose filling material | total |
|---|---|---|---|
| | | abundance | |
| *Cynodon dactylon* | 21 | 3 | 24 |
| *Geum urbanum* | 20 | 3 | 23 |
| *Plantago lanceolata* | 6 | 7 | 13 |
| **total** | **47** | **13** | **60** |

*Table 51 Wall base joint: top ten species per sun exposure level.*

| top ten species per substratum | abundance |
|---|---|
| **sun** | |
| *Taraxacum officinale* aggr. | 184 |
| *Setaria viridis* | 39 |
| *Sonchus oleraceus* | 30 |
| *Geranium robertianum* | 22 |
| *Cymbalaria muralis* | 21 |
| *Cynodon dactylon* | 19 |
| *Sisymbrium officinale* | 19 |
| *Polygonum mite* | 18 |
| *Carex divulsa* | 16 |
| *Oxalis corniculata* | 15 |
| *Poa annua* | 15 |
| **partial shade** | |
| *Taraxacum officinale* aggr. | 31 |
| *Taraxacum* sp. | 28 |
| *Carex* sp. | 26 |
| *Geum urbanum* | 26 |
| Mosses | 22 |
| *Senecio vulgaris* | 18 |
| *Cotoneaster* sp. | 14 |
| *Sagina procumbens* | 14 |
| *Galinsoga quadriradiata* | 13 |

| top ten species per substratum | abundance |
|---|---|
| *Poa annua* | 12 |
| *Melissa officinalis* | 12 |
| *Origanum vulgare* | 12 |
| **shade** | |
| *Taraxacum officinale* aggr. | 28 |
| Mosses | 8 |
| *Poa annua* | 8 |
| *Meconopsis cambrica* | 6 |
| *Cynodon dactylon* | 5 |
| *Poa pratensis* aggr. | 4 |
| *Veronica* cf. *cymbalaria* | 3 |
| *Sonchus oleraceus* | 3 |
| *Mycelis muralis* | 3 |
| *Hieracium murorum* aggr. | 2 |
| *Hedera helix* | 2 |
| *Senecio vulgaris* | 2 |
| *Lamium galeobdolon* subsp. *galeobdolon* | 2 |
| **total** | **702** |

*Table 52 Wall base joint: on 2 or 3 sun exposure levels.*

| species | sun | partial shade | shade | total |
|---|---|---|---|---|
| | | abundance | | |
| *Taraxacum officinale* aggr. | 184 | 31 | 28 | 243 |
| Mosses | 7 | 22 | 8 | 37 |
| *Poa annua* | 15 | 12 | 8 | 35 |
| *Sonchus oleraceus* | 30 | 1 | 3 | 34 |
| *Oxalis corniculata* | 15 | 9 | 1 | 25 |
| *Senecio vulgaris* | 4 | 18 | 2 | 24 |
| *Crepis capillaris* | 1 | 2 | 1 | 4 |
| *Geum urbanum* | 8 | 26 | | 34 |
| *Carex* sp. | 6 | 26 | | 32 |
| *Origanum vulgare* | 1 | 12 | | 13 |
| *Lapsana communis* | 2 | 11 | | 13 |
| *Daucus carota* | 2 | 6 | | 8 |
| *Geranium robertianum* | 22 | 4 | | 26 |
| *Plantago lanceolata* | 10 | 4 | | 14 |
| *Hypochaeris radicata* | 6 | 4 | | 10 |
| *Primula acaulis* | 2 | 4 | | 6 |
| *Rosa* sp. | 1 | 4 | | 5 |
| *Cymbalaria muralis* | 21 | 2 | | 23 |
| *Lactuca serriola* | 4 | 2 | | 6 |
| *Erigeron annuus* | 2 | 2 | | 4 |
| *Sedum spurium* | 1 | 2 | | 3 |
| *Festuca* sp. | 1 | 2 | | 3 |
| *Conyza canadensis* | 11 | 1 | | 12 |
| *Polygonum aviculare* | 1 | 1 | | 2 |
| *Cynodon dactylon* | 19 | | 5 | 24 |
| *Poa pratensis* aggr. | 1 | | 4 | 5 |
| *Hieracium* sp. | 5 | | 1 | 6 |
| *Sonchus asper* | 4 | | 1 | 5 |
| *Diplotaxis muralis* | 2 | | 1 | 3 |
| *Carpinus betulus* | 1 | | 1 | 2 |
| *Hedera helix* | | 5 | 2 | 7 |
| **total** | **389** | **213** | **66** | **668** |

*Table 53 Wall base joint: top ten species per water exposure level.*

| top ten species per water exposure level | abundance |
|---|---|
| **exposed to rain** | **505** |
| *Taraxacum officinale* aggr. | 228 |
| *Setaria viridis* | 39 |
| Mosses | 37 |
| *Sonchus oleraceus* | 33 |
| *Geum urbanum* | 33 |
| *Carex* sp. | 32 |
| *Taraxacum* sp. | 28 |
| *Geranium robertianum* | 26 |
| *Poa annua* | 25 |
| *Cynodon dactylon* | 24 |
| **exposed to trickling water** | **58** |
| *Taraxacum officinale* aggr. | 15 |
| *Galinsoga quadriradiata* | 13 |
| *Poa annua* | 10 |
| *Oxalis corniculata* | 5 |
| *Hedera helix* | 4 |
| *Senecio vulgaris* | 3 |
| *Stellaria media* aggr. | 3 |
| *Polygonum aviculare* | 2 |
| *Sonchus oleraceus* | 1 |
| *Geum urbanum* | 1 |
| *Galinsoga parviflora* | 1 |
| **total** | **563** |

*Table 54 Wall base joint: species exposed to rain an trickling water.*

| species | exposed to rain | exposed to trickling water | total |
|---|---|---|---|
| | | abundance | |
| *Geum urbanum* | 33 | 1 | 34 |
| *Sonchus oleraceus* | 33 | 1 | 34 |
| *Senecio vulgaris* | 21 | 3 | 24 |
| *Hedera helix* | 3 | 4 | 7 |
| *Taraxacum officinale* aggr. | 228 | 15 | 243 |
| *Oxalis corniculata* | 20 | 5 | 25 |
| *Poa annua* | 25 | 10 | 35 |
| **total** | **363** | **39** | **402** |

*Table 55 Wall base joint: top ten species per joint size.*

| top ten species per joint size | abundance |
|---|---|
| **< 0.005 m** | **429** |
| *Taraxacum officinale* aggr. | 202 |
| *Carex* sp. | 32 |
| Mosses | 29 |
| *Taraxacum* sp. | 28 |
| *Sonchus oleraceus* | 28 |
| *Oxalis corniculata* | 24 |
| *Cymbalaria muralis* | 23 |
| *Senecio vulgaris* | 22 |
| *Geranium robertianum* | 21 |
| *Poa annua* | 20 |
| **>= 0.005m** | **188** |
| *Taraxacum officinale* aggr. | 41 |
| *Setaria viridis* | 39 |
| *Polygonum mite* | 18 |
| *Geum urbanum* | 16 |

| top ten species per joint size | abundance |
|---|---|
| *Carex divulsa* | 16 |
| *Poa annua* | 15 |
| *Veronica peregrina* | 13 |
| *Galinsoga quadriradiata* | 13 |
| *Cynodon dactylon* | 9 |
| Mosses | 8 |
| **total** | **617** |

*Table 56 Wall base joint: species growing on both joint sizes.*

| species | < 0.005 m | >= 0.005m | total |
|---|---|---|---|
| | abundance | | |
| *Taraxacum officinale* aggr. | 202 | 41 | 243 |
| Mosses | 29 | 8 | 37 |
| *Poa annua* | 20 | 15 | 35 |
| *Sonchus oleraceus* | 28 | 6 | 34 |
| *Geum urbanum* | 18 | 16 | 34 |
| *Geranium robertianum* | 21 | 5 | 26 |
| *Oxalis corniculata* | 24 | 1 | 25 |
| *Senecio vulgaris* | 22 | 2 | 24 |
| *Cynodon dactylon* | 15 | 9 | 24 |
| *Veronica peregrina* | 1 | 13 | 14 |
| *Conyza canadensis* | 11 | 1 | 12 |
| *Daucus carota* | 7 | 1 | 8 |
| *Hedera helix* | 2 | 5 | 7 |
| *Primula acaulis* | 3 | 3 | 6 |
| *Hieracium* sp. | 5 | 1 | 6 |
| *Poa pratensis* aggr. | 1 | 4 | 5 |
| *Circaea lutetiana* | 1 | 4 | 5 |
| *Rosa* sp. | 3 | 2 | 5 |
| *Crepis capillaris* | 3 | 1 | 4 |
| *Glechoma hederacea* | 1 | 3 | 4 |
| *Erigeron annuus* | 3 | 1 | 4 |
| *Sedum spurium* | 1 | 2 | 3 |
| *Euphorbia peplus* | 1 | 1 | 2 |
| *Polygonum aviculare* | 1 | 1 | 2 |
| *Anagallis arvensis* | 1 | 1 | 2 |
| **total** | **424** | **147** | **571** |