Phyton (Horn, Austria)	**Vol. 48**	Fasc. 1	133–154	29. 8. 2008

URban Biotopes of Aotearoa New Zealand (URBANZ) (III): Spontaneous Urban Wall Vegetation in Christchurch and Dunedin

By

Diederik de NEEF*), Glenn H. STEWART **) and Colin D. MEURK***)

With 6 Figures

Received May 15, 2008

Key words: Floristics, neophytes, vegetation, urban walls. – Flora of New Zealand.

Summary

NEEF D. DE, STEWART G. H. & MEURK C. D. 2008. Urban biotopes of Aotearoa New Zealand (URBANZ) (III): Spontaneous urban wall vegetation in Christchurch and Dunedin. – Phyton (Horn, Austria) 48(1): 133–154, with 6 figures.

The vegetation of urban walls in New Zealand's cities has been little studied. We investigated the occurrence of wall vegetation in Christchurch and Dunedin cities, and determined whether vegetation patterns could be distinguished. This is a contribution to the ecological knowledge base that enables the development of management tools aimed at preserving and enhancing New Zealand urban biodiversity.

Walls were randomly selected with the only requirement that vegetation was present. In addition to plant species presence and abundance at different wall heights, wall characteristics including substrate type, aspect, orientation, and colour were also recorded. Due to high species diversity and low abundance, data analysis was generally carried out at the taxonomic level of orders.

*) Mr. Diederik de NEEF, Department für Integrative Biologie und Biodiversitätsforschung, Universität für Bodenkultur, Austria, Europe; e-mail: diederik.deneef@gmail.com

**) Prof. Dr. Glenn H. STEWART, Environment Society & Design Division, Lincoln University, P.O. Box 84, Christchurch 7647, New Zealand; e-mail: stewartg@lincoln.ac.nz and New Zealand Research Centre for Urban Ecology, 178 Days Road, Springston RD4, Christchurch 7674, New Zealand; e-mail: glenn01@xtra.co.nz

***) Dr. Colin MEURK, Landcare Research, P.O. Box 40, Lincoln, 7640 New Zealand; e-mail: meurkc@landcareresearch.co.nz

The majority of species on urban walls were non-native; 85.5% (100 of 117) and 91.4% (64 of 70) of species in Christchurch and Dunedin respectively. Species diversity is high, but repeat occurrences low; 76.5% and 50% of the species occur in less then 5% of the samples for Christchurch and Dunedin respectively. In both cities the orders *Asterales, Brassicales, Caryophyllales*, and *Poales* were predominant. High incidence of species in the crack between base of wall and pavement indicated more favourable conditions or enhanced accessibility compared to other parts of the wall habitat. Lichens, and to some extent bryophytes, seemed to prefer the higher areas of the wall; lichens on rock surfaces but bryophytes preferring the joints. In Christchurch, lichens were rare in the urban-industrial centre of the city. Overall the observed wall vegetation is relatively similar between the two cities.

Zusammenfassung

NEEF D. DE, STEWART G. H. & MEURK C. D. 2008. Urban biotopes of Aotearoa New Zealand (URBANZ) (III): Spontaneous urban wall vegetation in Christchurch and Dunedin. [Urbane Biotope in Aotearoa Neuseeland (URBANZ) (III): Spontane Vegetation auf städtischen Mauern in Christchurch und Dunedin]. – Phyton (Horn, Austria) 48(1): 133–154, mit 6 Abbildungen.

Die Vegetation auf urbanen Mauern in Neuseelands Städten ist bisher wenig studiert. Wir untersuchten Mauer-Vegetation in Christchurch und Dunedin und untersuchten, welche Vegetations-Muster unterschieden werden können. Die Arbeit ist ein Beitrag zu den Grundlagen der Stadtökologie und soll Management-Pläne zu Schutz und Förderung städtischer Biodiversität unterstützen. Die Mauern wurden nach dem Zufallsprinzip ausgewählt, mit dem Vorhandensein von Vegetation als einziger Voraussetzung. Zusätzlich zur Anwesenheit und Häufigkeit von Pflanzenarten in verschiedenen Mauer-Höhen, wurden Charakteristika der Mauern wie Substrattyp, Exposition und Farbe ebenfalls berücksichtigt. Wegen der hohen Artenvielfalt bei geringer Häufigkeit, erfolgte die Auswertung hauptsächlich auf der Ebene der Ordnung. Die Mehrzahl der Arten städtischer Mauern waren nicht einheimisch: 85,5 % (100 von 117) und 91,4 % (64 von 70) der Arten in Christchurch bzw. Dunedin. Die Arten-Diversität ist hoch, aber die Zahl wiederholter Vorkommen ist gering; 76,5 % der Arten in Christchurch bzw. 50 % in Dunedin kommen in weniger als 5 % der Aufnahmen vor. In beiden Städten waren die Ordnungen *Asterales, Brassicales, Caryophyllales* und *Poales* vorherrschend. Die Häufigkeit der Arten in den Spalten zwischen Mauerbasis und Pflasterung deutet auf günstige Bedingungen oder leichtere Zugänglichkeit im Vergleich zu anderen Teilen der Mauerstandorte hin. Flechten und zu einem gewissen Grade auch Moose bevorzugen höhere Teile der Mauern, Flechten die Steinoberflächen, Moose die Fugen. In Christchurch waren Flechten im Industrie-Zentrum der Stadt selten. Im Großen und Ganzen ist die Mauervegetation in beiden Städten ähnlich.

1. Introduction

International recognition of world wide loss of biodiversity led to the multilateral Convention on Biological Diversity in 1992. New Zealand ratified the convention and has developed a biodiversity strategy and a multitude of conservation programmes to protect its own unique biological diversity. These programmes focus largely on (pristine) natural areas while an increasing body of literature points to the importance of nature conservation in urban areas and the associated environmental, social, and economic benefits (SAVARD & al. 2000, ZERBE & al. 2002, BREUSTE 2004, TURNER & al. 2004, MILLER 2005, DUNN & al. 2006). The magnitude of potential benefits are spelled out by the fact that world wide approximately half the population lives in urban areas with future estimates reaching 60% by 2030 (UN 2006). The proportion of New Zealand's urban population is even higher at 77.8% (STATISTICS NEW ZEALAND 2006).

Nature conservation in urban areas appears to be an oxymoron since it is widely believed that urbanization is detrimental to the natural environment (MCKINNEY 2002). Cities can host a surprising biological diversity (MEURK 2005), although a study of five metropolitan areas showed that the majority of urban populations live in areas of deprived biodiversity (TURNER & al. 2004). The development of Low Impact Urban Design and Development (LIUDD) technologies in New Zealand aims to reduce/eliminate adverse effects of urban development and promote enhanced biodiversity in urban areas. Of particular interest is the direct interaction between humans and nature. In this sense nature is not a remote fenced-in abstraction, but surrounds the urbanites in their daily environment. Several authors have stressed the importance of exposure to nature as this will increase the probability that people will participate more readily in nature conservation efforts (MILLER 2005, DUNN & al. 2006).

World wide, wall vegetation has attracted the attention of many botanists, particularly in Europe where records of wall vegetation go as far back as 1597 (WOODELL 1979). Earlier studies investigating wall vegetation have focused on walls of substantial age since "old walls provide many habitats suitable for plants" (RISBETH 1948). SEGAL 1969 estimated that good examples of wall vegetation are most likely found on walls 100 to 500 years old. Colonisation of walls can take place rapidly however, in a 3 to 5 year period as others have observed (DARLINGTON 1981, HOLZNER pers. comm). New Zealand's urban walls therefore provide a novel study area on which the occurrence of native species is of particular interest. By randomly selecting urban walls in two New Zealand cities (Christchurch and Dunedin) and recording occurrence and several environmental variables, the presence of patterns in wall vegetation are determined. The data was analysed on presence of spatial patterns on a city wide scale, patterns resulting from wall habitat factors, and vegetation patterns (e.g. frequency, abundance, etc).

The vegetation growing on urban walls has been investigated numerous times in Europe throughout the last centuries. The publications mentioned by WOODELL 1979 BRANDES 1992 and SUKOPP 2002 give an overview of historical studies carried out and are briefly described to give insight into the historical background of wall flora studies in Europe. In summary: WOODELL 1979 noted that as early as 1597 J. GERARD mentioned several plant species growing on the walls of London, to which many wall dwelling plants were added by W. CURTIS in 1777–98. In continental Europe floristic studies of the Colosseum in Rome started in 1643 by PANAROLI, followed by SEBASTIANI (1815), DEAKIN (1855), and MAZZANTI (1874–1878) (SUKOPP 2002, CANEVA & al. 2003). Other studies in Italy were carried out by DE ROSA (1915), GABELLI (1915), and BÉGIUNOT (1911–16) (BRANDES 1992). Walls in France were studied by JOURDAN (1866, 1867, 1872) (BRANDES 1992) and RICHARD (1888) (SUKOPP 2002), whereas BARNEWITZ (1898) studied the wall vegetation of the city walls of Brandenburg (BRANDES 1992).

Most studies mentioned focused on old walls where vegetation has had a great deal of time to colonize walls that are built of material more prone to gradual decomposition compared to modern building materials. This is a significant difference with what is encountered in New Zealand cities. Modern building materials are less prone to weathering processes essential for the establishment of vegetation (SEGAL 1969). In both Christchurch and Dunedin relatively few buildings exist that exceed 100 hundred years. This means that the majority of the walls are built with harder and more durable materials than were used around 150 years ago. Additionally, many walls have a protective layer of paint again reducing the speed at which walls decay and wall flora can develop. However, WOODELL 1979 mentioned that even unlikely places such as concrete walls are rapidly colonized when cracks occur. Our study therefore provides an important comparison to the "older" walls of Europe.

Urban ecosystems have received relatively little attention in ecological studies compared to natural ecosystems (COLLINS & al. 2000) especially outside Europe. As a result gaps exist in knowledge and empirical data on which management tools and decisions that aim to enhance urban biodiversity are based. In an effort to fill these gaps, this study aims to determine the occurrence and patterns of wall vegetation in two New Zealand cities. It is the first urban wall vegetation study in New Zealand and aims to provide a basis for understanding the ecology of the specialised wall habitat and provide knowledge to help identify potential for the conservation of biological diversity in this particular urban biotope. The results of this study will be used in combination with other recent studies focusing on lawns (HORNE & al. 2005, STEWART & al. in prep.) and urban forests (STEWART & al. 2004, STEWART & al. in prep.). This paper is the third in a series describing the structure, composition, dynamics, biodiversity conservation imperatives, and management of urban ecosystems in New Zealand (part I focuses on lawns, and part II woodlands).

2. Study Areas

Christchurch and Dunedin cities are situated on the east coast of New Zealand's South Island. Christchurch is the second largest urban centre in New Zealand with a population of 360,765 (STATISTICS NEW ZEALAND 2006). Christchurch city covers 45,240 hectares, of which approximately 17,000 hectares are used for urban land use purposes (CHRISTCHURCH CITY COUNCIL 2000). The area is roughly demarcated by the Pacific Ocean to the east, the Waimakariri River to the north, and the Port Hills to the south. The latter are a characteristic topographical feature that contrasts with the otherwise flat plains on which the city is situated. The original vegetation of tussock grass- and shrub-land, dunes, freshwater wetlands, brackish salt marshes, and pockets of indigenous forest has largely been replaced by exotic vegetation types (MEURK & NORTON 1988). The climate is moderate and is influenced by the ocean and Southern Alps. Mean maximum temperature for January is 22.5° C, mean minimum temperature for July is 1.9° C, and annual precipitation is 648 mm (NIWA 2007). Warm desiccating föhn winds caused by the Southern Alps are frequent and prevail particularly in summer, whereas cool south-westerlies are more common during winter.

Dunedin is situated 400 km south of Christchurch. It is the sixth largest urban centre of New Zealand with a population of 110,997 (STATISTICS NEW ZEALAND 2006). Dunedin city covers 327,400 hectares, of which 6,381 hectares have urban land uses (DUNEDIN CITY COUNCIL 2003). The city centre is located at the south end of Otago Harbour and is situated in a central part of an ancient volcanic system. This rather hilly environment results in a wide variety of microclimates. As in Christchurch, most of the original vegetation present before colonization has disappeared. The climate in Dunedin is temperate, and moister than that of Christchurch, and is influenced by the proximity of the ocean and Southern Alps. Mean monthly maximum temperature is 18.9° C, mean monthly minimum temperature is 3.2° C, and annual precipitation is higher than Christchurch at 812 mm (NIWA 2007). It is important to note that although Dunedin receives relatively low annual precipitation, it is renowned for its drizzle which raises relative humidity. Similar to Christchurch, the warm desiccating föhn winds occur in summer, while cold air currents from the south prevail in winter.

3. Methods

3.1 Sampling Strategy

A preliminary survey of wall vegetation in Christchurch revealed a low frequency of occurrence of plants growing on the city walls. Random sampling, as used in the preliminary survey, applied to such populations can be expected to return a high proportion of 'empty' samples. The probability of encountering native species would be smaller yet due to the higher number of exotic species in the city. To overcome this we established random locations, but instead of sampling the nearest wall, we sampled the nearest wall with vegetation present.

3.2 Number of Samples

The number of samples collected was related to the approximate size of the study areas. This was done because the distribution of walls across the city is fairly equal. A one square kilometre (km^2) grid was projected on each city map and all cells with more then approximately half of its surface indicated as urban built area were included. For Christchurch and Dunedin this resulted in 214 and 54 cells respectively. A minimum of 30% coverage of the total city area was set leading to a minimum of 64.2 samples for Christchurch and 16.2 for Dunedin. We increased sampling effort slightly, especially in the case of Dunedin, to insure a representative sample size (46% coverage).

3.3 Sample Unit

Sampling in most vegetative studies usually involves quadrats or transects (Hill & al. 2005); in this study we chose the sample unit as the urban wall. Walls were included that fulfilled the following conditions: must be constructed of stone, concrete, or brick (i.e. metal and wooden walls were excluded); must host at least one species at two or more locations, or >2 species; and the base of the wall must contain a wall or pavement habitat. The first condition is based on the observation that few species grow on wooden or metal (e.g. corrugated iron fences) walls, and are unlikely to develop there due to unfavourable conditions. The second condition served to prevent the return of too many 'empty' samples as previously discussed. The last condition excludes the vegetation of other adjacent habitat types, for example lawns, which would not be representative of the wall habitat. Any type of wall was included – building walls, free standing walls, fences, retaining walls, and bridge walls.

3.4 Variables Recorded

The randomly selected locations were marked on a city map, however the locations did not necessarily correspond to the locations where the sample was taken. In some cases significant effort was required to find a wall that fulfilled the requirements above. In such cases, which were more the rule then exception, it was necessary to record the GPS coordinates to enable a spatial representation of samples.

Substrate (construction material), aspect (degrees from north), colour (white, pale, medium dark, and black), age (based on the presence of historical buildings and visible deterioration of the wall) were recorded. All species of vascular plants, bryophytes and lichens were recorded. For each different species a specimen was collected for identification. For each species, abundance was recorded on a 5-point scale from rare→ occasional→ frequent→ abundant→ dominant. For each plant we recorded: rooting substrate (crevice, crack, ledge, joint, and surface), height above the ground (0.0 – 0.3 (G0), 0.3 – 2.0 (G1), 2.0 – 5.0 (G2), 5.0 – 12 (G3), >12m (G4)), orientation (whether a plant occurred on a vertical, horizontal, sloping, or a junction of vertical and horizontal or 2 vertical surfaces surfaces), obvious signs of management activities (e.g. weeding, herbicide application). Finally, we used the Flora of New Zealand series to determine which species were native and which were non-native

(MOORE & EDGAR 1970, HEALY & EDGAR 1980, ALLAN 1982, WEBB & al. 1988, EDGAR & CONNOR 2000).

3.5 Data Analysis

We conducted a single variable analysis and a multi-variable analysis of occurrence and abundance. We conducted a principal component analysis (PCA) to reduce the dimensions of our data set (SHLENS 2003). It is often difficult to detect the underlying structure of highly dimensional data sets and PCA attempts to determine a linear combination of the original data that best re-expresses the data set (SHLENS 2003). This involves an eigen-analysis of a correlation matrix. PCA assumes linearity which simplifies the mathematical problem by restricting the set of potential bases and formalizing the assumption of continuity in a data set (SHLENS 2003). A second assumption of PCA is that the directions with the largest variances are most important. Each vector can be rank-ordered according to the corresponding variances. A third assumption is that the principal component is an orthonormal matrix enabling the application of linear algebra.

4. Results

4.1 Wall Vegetation of Christchurch and Dunedin

In Christchurch the seventy sample locations contained 838 observations of vascular and non vascular species. 117 species were identified over 41 families and 24 orders (Table 1), including 17 native species. Approximately 90 of the 115 species occurred in <5 sample locations. Dicotyledons were the most represented (57%) followed by lichens (19%), monocotyledons (14%), and bryophytes (7%). Ferns, liverworts, and algae make up the remainder. In Dunedin twenty-five sample locations contained 326 observations. 70 species were identified distributed over 26 families and 18 orders, including 6 native species. Thirty-five of the 70 species occurred in <5 sample locations, 11 species in 5–10 locations and 16 species in 10–25 locations. Dicotyledons were recorded most often (64%) followed by monocotyledons (14%), bryophytes (10%), and lichens (10%). Ferns and liverworts made up the remainder.

In Christchurch, foliose lichens occured in >50% of the samples. *Sonchus oleraceus*, bryophytes, crustose lichens, *Cardamine hirsuta, Poa annua, Stellaria media*, and *Euphorbia peplus* occurred in 25% to 50% of the samples. *Senecio vulgaris, Trifolium* sp., *Hypochoeris radicata, Cordyline australis, Solanum nigrum, Cerastium* sp., *Crepis capillaris, Oxalis* sp., *Veronica* sp, and *Galium aparine* occurred in 10% to 25%. *Cordyline australis* was the first native species that occurred relatively frequently (in 15% of the samples). This was followed by *Coprosma robusta* and *Dodonaea viscosa* with incidences of 8% and 5%, respectively. The remaining 14 native species occurred in <5% of the samples, often only once or twice.

In Dunedin, *Cardamine hirsuta*, bryophytes, and *Sonchus oleraceus* occurred in >50% of the samples, while crustose lichens, *Poa annua*, fo-

Table 1. Vascular plant species and higher taxonomic groupings observed growing on Christchurch and Dunedin city walls. * = native species.

	Family	Christchurch species	Dunedin species
Pteridophyta			
Filicales	*Aspleniaceae*	*Asplenium flabellifolium**, *Asplenium oblongifolium**, *Asplenium* sp.*	
	Dryopteridaceae	*Athyrium filix-femina, Dryopteris filix-mas*	*Dryopteris filix-mas*
Moncotyledones			
Asparagales	*Agavaceae*	*Cordyline australis**	*Cordyline australis*
	Iridaceae		*Crocosmia* sp.
	Orchidaceae	*Microtis unifolia**	
Liliales	*Liliaceae*	*Agapanthus* sp.	
Poales	*Cyperaceae*	*Cyperus* sp.	*Cyperus eragrostis*
	Poaceae	*Agrostis capillaris, Bromus* sp., *Dactylis glomerata, Digitaria sanguinalis, Elytrigia repens, Festuca rubra, Festuca* sp., *Holcus lanatus, Lolium perenne, Poa annua, Poa imbecilla**, *Poa* sp.	*Bromus* sp., *Bromus wildenowii, Dactylis glomerata, Festuca rubra, Lolium perenne, Poa annua*
	Gramineae	Unidentified grasses	
Ranunculales	*Fumariaceae*	*Fumaria* sp.	*Fumaria* sp.
	Ranunculaceae	*Ranunculus* sp., *Aquilegia vulgaris*	*Aquilegia vulgaris, Ranunculus repens*
Dicotyledones			
Apiales	*Apiaceae*	*Daucus* sp., *Hydrocotyle heteromeria**	
	Araliaceae	*Hedera helix*	
Asterales	*Asteraceae*	*Achillea millefolium, Bellis perennis, Chrysanthemum* sp., *Cirsium vulgare, Conyza albida, Conyza bilbaoana, Conyza* sp., *Crepis capillaris, Erigeron karvinskianus, Erigeron* sp., *Hypochoeris radicata, Mycelis muralis, Pseudognaphalium luteoalbum**, *Senecio cineraria, Senecio glomeratus**, *Senecio* sp. , *Senecio vulgaris, Soliva* sp., *Sonchus asper, Sonchus oleraceus, Taraxacum officinale,* Unidentified vascular plants	*Achillea millefolium, Bellis perennis, Chrysanthemum* sp., *Cirsium* sp., *Cirsium vulgare, Conyza* sp., *Cotula australis**, *Crepis capillaris, Erigeron karvinskianus, Hieracium pilosella, Hypochoeris radicata, Pseudognaphalium luteoalbum**, *Senecio dunedinensis**, *Senecio glomeratus**, *Senecio vulgaris, Sonchus oleraceus, Taraxacum officinale, Lapsana communis*
Boraginales	*Boraginaceae*	*Echium vulgare*	
Brassicales	*Brassicaceae*	*Capsella bursa-pastoris, Cardamine hirsuta, Coronopus didymus, Lepidium* sp., *Lobularia maritima,* Unidentified vascular plants	*Brassica* sp., *Capsella bursa-pastoris, Cardamine hirsuta, Coronopus didymus, Coronopus* sp., *Lepidium* sp., *Sisymbrium* sp.

Table 1. Continuation

Caryophyllales	*Aizoaceae*	*Disphyma australe**, *Tetragonia trigyna**	
	Amaranthaceae	*Amaranthus* sp.	*Amaranthus* sp.
	Caryophyllaceae	*Cerastium fontanum*, *Cerastium glomeratum*, *Cerastium* sp., *Polycarpon tetraphyllum*, *Sagina apetala*, *Sagina procumbens*, *Silene gallica*, *Stellaria media*, *Chenopodium album*	*Cerastium glomerata*, *Sagina apetala*, *Sagina procumbens*, *Spergularia media*, *Stellaria media*
	Polygonaceae	*Fallopia convolvulus*, *Polygonum aviculare*, *Rumex acetosella*, *Portulaca oleracea*	*Rumex acetosella*
Dipsacales	*Caprifoliaceae*	*Sambucus nigra*	
	Valerianaceae	*Centranthus ruber*	*Centranthus ruber*
Fabales	*Fabaceae*	*Cytisus scoparius*, *Trifolium* sp.	*Chamaecytisus palmensis*, *Trifolium repens*, *Trifolium* sp.
Fagales	*Betulaceae*	*Betula* sp.	*Betula pendula*, *Betula* sp.
Gentianales	*Apocynaceae*	*Vinca major*	
	Rubiaceae	*Coprosma robusta**, *Galium aparine*	*Coprosma robusta**, *Galium aparine*
Geraniales	*Geraniaceae*	*Eriodium* sp., *Geranium sessiliflorum**, *Geranium* sp.	*Geranium robertianum*
Lamiales	*Lamiaceae*	*Lamium amplexicaule*, *Lamium purpureum*, *Rosmarinus officinalis*	*Lamium purpureum*, *Lamium* sp.
	Oleaceae	*Ligustrum* sp.	
	Plantaginaceae	*Plantago coronopus*, *Plantago lanceolata*, *Plantago major*	*Plantago lanceolata*
	Scrophulariaceae	*Cymbalaria muralis*, *Digitalis purpurea*, *Linaria purpurea*, *Veronica* sp.	*Buddleja* sp., *Cymbalaria muralis*, *Digitalis purpurea*, *Linaria purpurea*, *Veronica* sp.
Malpighiales	*Euphorbiaceae*	*Euphorbia peplus*	*Euphorbia peplus*
	Violaceae	*Viola* sp., *Viola tricolor*	*Viola odorata*
Malvales	*Malvaceae*	*Hoheria populnea**, *Malva* sp., *Malva sylvestris*	
Myrtales	*Onagraceae*	*Epilobium ciliatum*, *Epilobium cinereum**, *Epilobium* sp.	*Epilobium ciliatum*, *Epilobium nummulariifolium**
Oxalidales	*Oxalidaceae*	*Oxalis exilis**, *Oxalis* sp.	*Oxalis* sp.
Rosales	*Rosaceae*	*Cotoneaster simonsii*, *Crataegus monogyna*, *Prunus* sp., *Rosa* sp.	*Cotoneaster* sp.
Sapindales	*Aceraceae*	*Acer pseudoplatanus*	
	Sapindaceae	*Dodonaea viscosa**	
Saxifragales	*Crassulaceae*	*Aeonium haworthii*, *Cotyledon orbiculata*	*Sedum acre*, *Sedum* sp.
Solanales	*Convolvulaceae*	*Dichondra repens**, *Convolvulus* sp.	
	Solanaceae	*Solanum nigrum*, *Solanum* sp.	

liose lichens, *Hypochoeris radicata, Bromus* sp., *Senecio vulgaris, Stellaria media, Crepis capillaris*, and *Taraxacum officinale* occurred in 25% to 50% of the samples. The 10% to 25% category contained *Euphorbia peplus, Sagina procumbens, Veronica* sp., *Linaria purpurea, Festuca rubra, Cirsium vulgare, Epilobium nummulariifolium, Senecio dunedinensis, Cerastium glomeratum, Lamium purpureum, Trifolium* sp., *Brassica* sp., *Trifolium repens, Sisymbrium* sp., *Cotula australis*, and *Aquilegia vulgaris*. *Senecio dunedinensis* was the first native species and it occurred in >10% of the samples. The next native species, *Cordyline australis*, occurred in 8% and the remaining species were encountered only once.

Average abundance of single species is low in both cities. Some orders rise slightly above abundance class 'rare', but by far the majority of plant specimens recorded have a rare or occasional occurrence. Overall average abundance of plants on walls was higher in Dunedin than Christchurch, and especially so for *Asterales, Brassicales*, and *Caryophyllales*. *Poales* were abundant in both cities. In Christchurch the order *Asterales* consists of just one family, but contains the largest number of species (22). The orders *Caryophyllales, Poales*, and *Lamiales* follow, with each a relatively large number of species (16, 14, and 11 respectively) and families (4, 3, and 4 respectively).

4.2 Influence of Aspect

In Christchurch the abundance of species encountered on south facing walls was higher compared to other aspects which seem less favourable (Fig. 1.). In Dunedin plants were relatively evenly distributed on all aspects. The concentration on south-facing walls in Christchurch probably reflects the influence of a warmer, drier and less humid climate than Dunedin, south-facing aspects are more moist and therefore favoured by plants.

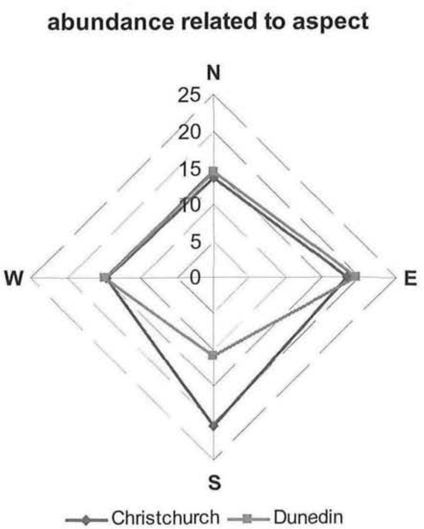

Fig. 1. Average abundance of wall vegetation in relation to aspect for Christchurch and Dunedin.

4.3 Influence of Wall Height

In both Christchurch and Dunedin species incidence was highest in height tier G-0 (c. 500 in Christchurch, 200 in Dunedin). Average abundance of species, however is higher in height tiers G-1 (c. 25 in Christchurch, c. 20 in Dunedin) and G-2 (c. 20 in Christchurch, c.15 in Dunedin). Average abundance on vertical and horizontal parts of the wall was higher than the base of the wall (Fig. 2). The incidence of plants at the base of the wall far exceeds the incidence of vegetation with different orientation in both study areas. In Dunedin no vegetation was recorded on sloping parts of a wall. Comparison with the incidence of specimens shows that a relatively small number occur on average between 'occasionally' and 'frequently'.

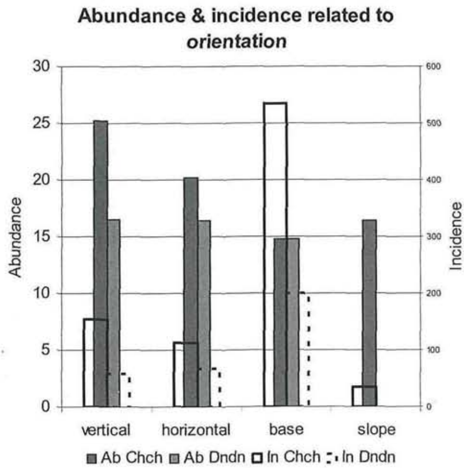

Fig. 2. Orientation related to average abundance and incidence for wall vegetation in Christchurch (Chch) and Dunedin (Dndn).

The abundance of species established higher on the wall is greater then those established at the base of the wall. This is strange considering that the conditions higher on the wall are assumed to be less favourable. The incidence shown in Fig. 3A and B explain this phenomenon. Incidence is calculated in proportion to the total number of observed specimens. Monocotyledons and dicotyledons occur predominantly at the base of the wall at height tier G-0, while lichens occur higher up on the wall. Often when lichens were observed they occurred abundantly, whereas many monocotyledons and dicotyledons were rare or occurred occasionally. This resulted in the high abundance on the upper height tiers of the wall (Fig. 3) which relates mainly to lichens.

4.4 Substrate

In both study areas concrete walls predominate, followed by basalt in Christchurch and granite in Dunedin. In Dunedin average abundance is fairly similar across all substrates (Fig. 4). In Christchurch concrete walls have a lower average abundance than basalt and granite.

4.5 Rooting Substrate

Plants are often found rooting in cracks in both study areas as the incidence in Fig. 4B shows. Average abundance in cracks is low compared to the other rooting substrates encountered.

4.6 Principal Component Analysis

The Christchurch dataset exhibited high species variability and had many dimensions, 61 variables in total. To reduce the number of dimen-

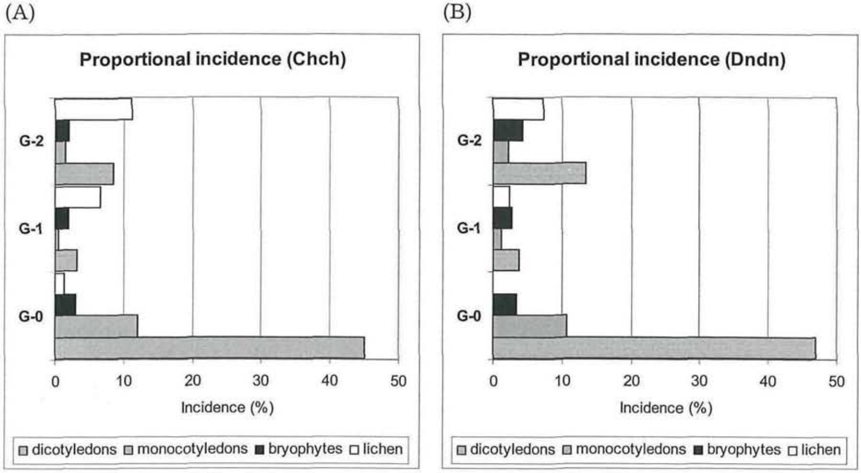

Fig. 3. Incidence of major groups related to wall height tiers in (A) Christchurch (Chch) and (B) Dunedin (Dndn).

sions a principal component analysis (PCA) was carried out. The accompanying eigenanalysis of the correlation matrix resulted in 37 major eigenvalues. The lower limit for the eigenvalues was conventionally set at 1.00 explaining a cumulative variance of 78.1% of the basic data matrix. The data collected in Dunedin showed a similar variability to Christchurch and the same method of analysis was applied. Dimensions were excluded below an eigenvalue of 1.00 resulting in 24 principal components explaining a cumulative variance of 80.4%.

All variables plotted outside the dashed circles of Fig. 5A and 5B have significant impact on the principal component and as such explain a relatively higher proportion of the data variance. Combinations of the other principal components (i.e. PC1&3, PC2&3, PC2&3 varimax normalized) show similar patterns. The most frequently occurring variables in these PC combinations are: substrate material basalt and concrete; colour shade category dark and pale; rooting substrate crack; orientation horizontal and base; and height tiers *G-0* and *G-2*. Less frequent variables are: substrate material concrete; rooting substrate surface and joint; orientation vertical; and height tier *G-1*. The remaining variables did not exceed the 0.5 limit explaining proportionally less variance in the data.

In the PCA solution of the Christchurch data the horizontal axis PC1 explains 8.8% of the variance. The seven variables (concrete, G-0, base, crack, G-2, surface and vertical, 11.7% of the total) explain 6.0% of the total variance, or 67.8% of the variance explained by PC1. As such, several gradients are represented by the PC1 axis. PC2 explains 4.1% of the total variance and is similarly predominated by environmental variables three

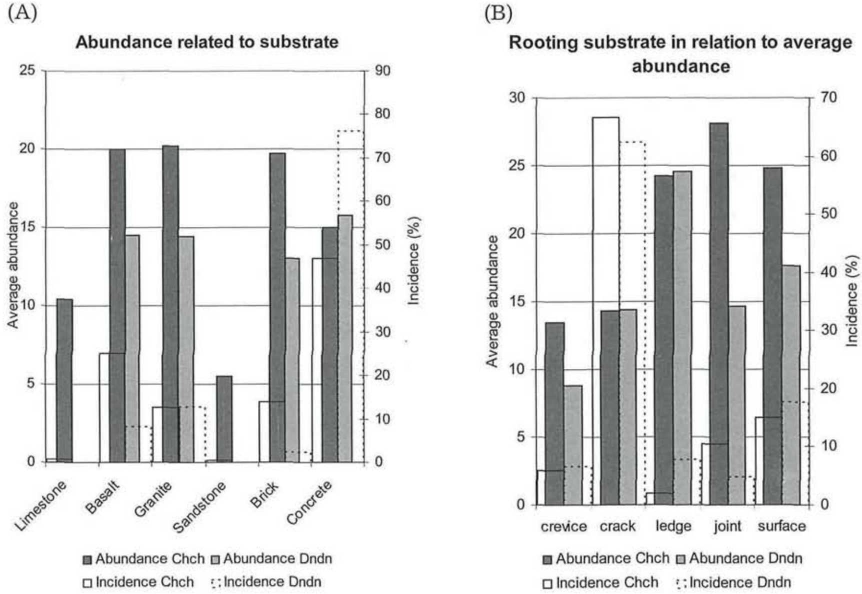

Fig. 4. Abundance and incidence of wall vegetation related to (A) substrate and (B) wall position in Christchurch (Chch) and Dunedin (Dndn).

of which (concrete, pale, dark) explain 1.8% of the total variance, or 43% of the variance explained by PC2. For Dunedin, PC1 axis explains 12.0% of the variation in six variables (G-2, G-0, vertical/horizontal, base and surface). Similar to the Christchurch study, these environmental variables explain 6.7% of the total variation, or 56.1% of the variation explained by PC1. PC2 axis explains 9.0% of the variance in the data. It is also predominated by environmental variables of which the four most significant ones (concrete, basalt, old and young) explain 6.7% of the total variance, or 56.1% of the variance explained by PC2.

Species distributions along the PCA axes were similar for Christchurch and Dunedin so Christchurch results only will be discussed here. A strong gradient along the PC1 axis shows the distribution of lichen occurring predominantly on the higher vertical surfaces of the sampled walls (height tier G-2 and not at all on G-0, Fig. 5A, 6A). Observations indicate lichens were recorded on the surface 69% of the time, on height tier G-2 (58%), and on vertical surfaces (56%). The few ferns that were recorded in Christchurch, 16 records in all, seem to occur under similar conditions as lichens. Occurring rather evenly along the PC1 gradient, mosses seem to grow well on different height tiers, rooting substrate, and orientation. However, closer inspection of the data does show a preference towards the base of the wall. Here larger quantities of particulate matter accumulate

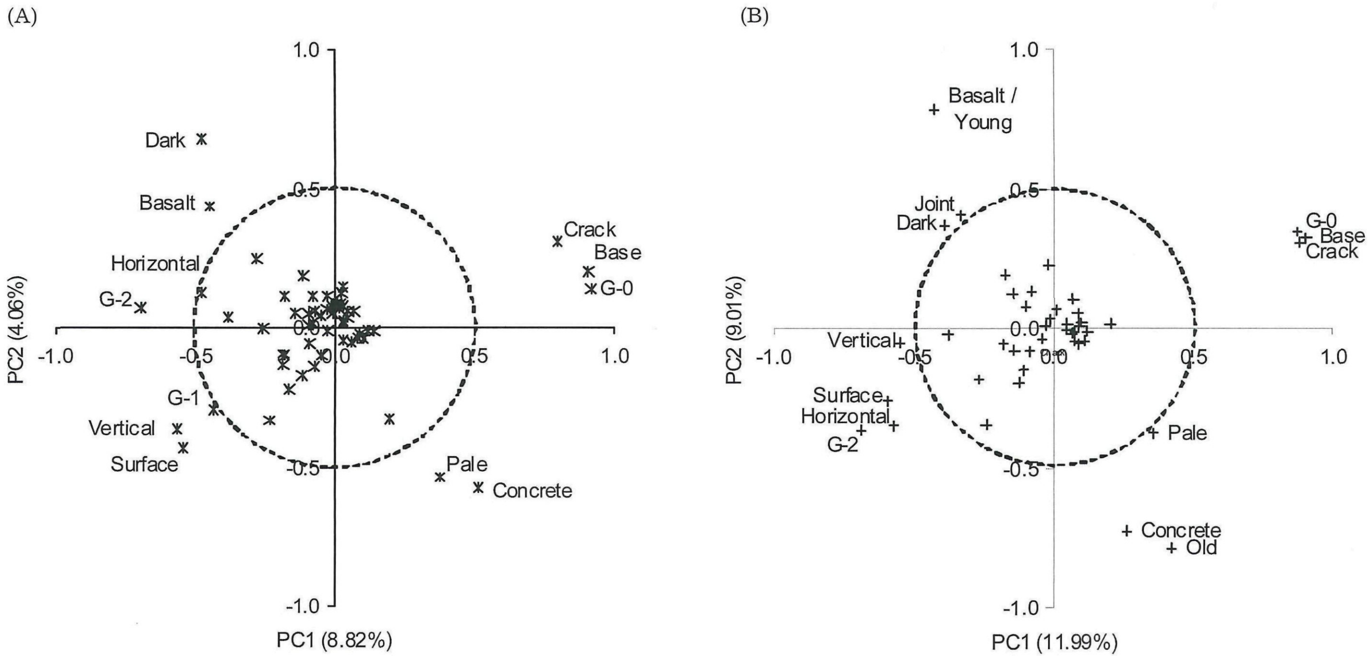

Fig. 5. PCA biplot showing wall variables for urban walls in (A) Christchurch and (B) Dunedin.

and moisture conditions are more favourable. As a result, establishment is easier and abundance greater. The plants that grow higher up on the wall tend to grow in joints; 45% of the total number of recorded mosses were found in joints. Monocotyledons and dicotyledons occur all along the PC1 but seem to lean towards G-0 height tier and base orientation. In general dicotyledons occur at the base of the wall (81%), on height tier G-0 (79%) in the crack between the wall and the pavement (86%).

The environmental gradient represented by the PC2 axis shows three main variables: colour shading is the dominant factor with pale shades at one end of the gradient and dark substrates at the other (Fig. 5A). Concrete walls occur on the same side of the spectrum as pale shading. Lichens seem to have a slight preference for lighter shade of substrate, whereas ferns, monocotyledons, and dicotyledons lean more towards darker shades (Fig. 6A). The relation between substrate and colour shading should be noted here. In the study area basalt and concrete substrates were most often encountered, 25% and 47% of the total records respectively. Concrete is situated at the same end of the PC2 gradient as pale, in contrast to dark. Basalt is dark volcanic rock thus directly related to colour shading. In addition, walls built of basalt rocks often are retaining walls situated in the Port Hills.

The ferns *Asplenium flabellifolium* and *A. oblongifolium* (and *Tetragonia trigyna*) are grouped towards one extreme of the PC1 gradient, while most monocot and dicot species are grouped at the other end (Fig. 6B). This probably indicates a preference for older (basalt), darker walls.

5. Discussion

The majority of species encountered in the study areas were ruderals. Although not 'typical' wall species, approximately a quarter of the species in both study areas occur on a list of plant communities characteristic of walls and wall tops in Austria (Forstner 1983). These facultative species are not restricted to the wall habitat however, but are common on virtually any type of wasteland. Walls in the urban centres of Christchurch and Dunedin in essence resemble vertical wastelands (e.g. railway tracks, empty building sites, rubble dumps) in that they are sparsely vegetated and frequently disturbed. The base of the wall, which is readily colonised in particular, hosts species common to wastelands.

Incidence of dicotyledons shows their predominant presence in both study areas, followed by the other major plant groupings, in similar proportions but different order. The explanation is probably found in plant traits/characteristics. It is interesting to note that among the species checked (84 and 51 for Christchurch and Dunedin respectively), many (c. 15–25%) are anemochorous. This is similar to earlier studies that found that the most common form of dispersal was by wind (Brandes 1992, Lisci & Pacini 1993, Duchoslav 2002). However, most checked species did not

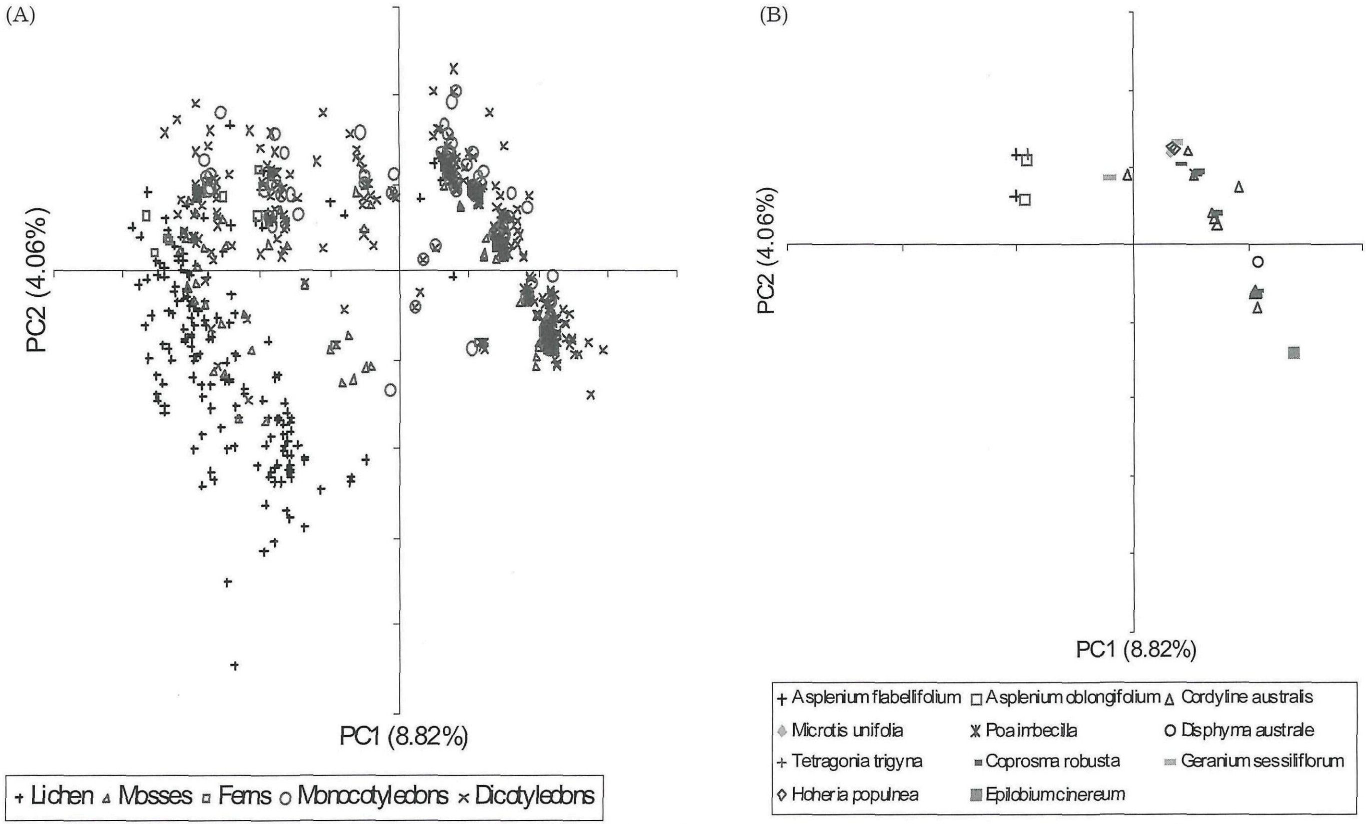

Fig. 6. PCA biplot showing (A) species by taxonomic groups for urban walls, Christchurch and (B) native species only for urban walls, Christchurch.

have a single means of dispersal. This is what WOODELL & ROSSITER 1959 also found, although their sample size was quite small. The most abundant family in both study areas was *Asteraceae* also reported previously by BRANDES 1992, DUCHOSLAV 2002, and PAVLOVA & TONKOV 2005. For explanation PAVLOVA & TONKOV 2005 refer to PYŠEK 1997 who states that: "the family is remarkably successful in terms of dispersal and establishment."

Low abundance is characteristic for wall vegetation (see WOODELL & ROSSITER 1959, SEGAL 1969, DUCHOSLAV 2002), and since no previous studies have been carried out in New Zealand comparisons cannot be made. SEGAL 1969 recorded the percentage coverage of plant communities (i.e. *Asplenium trichomanes, Parietaria judaica, Bromus madritensis*) growing on walls, which in extreme cases reached up to 70% cover, but more commonly averaged around 20% to 30%. Even these lower percentages were not encountered in our study, altough high abundance was observed in lichens higher on the wall. SEGAL did not include the base of the wall in his study since he studied typical vertical wall vegetation only. His percentages therefore relate to plants growing higher on the wall.

Explanations for low abundance in the study areas in general are to be found in the unfavourable habitat conditions. When again comparing with SEGAL's study the difference in location selection becomes apparent. Especially the following criteria for the selection of walls: "...built of stones or bricks, jointed with not too hard a type of mortar, of fairly considerable age, and situated in an environment in which no prolonged period of drought prevails." These requirements to a large extent sum up the environmental factors that determine the success of any vegetative establishment. Under such conditions abundance can be expected to be higher. Conversely, when these conditions are not fulfilled, vegetative establishment will be less successful and abundance of established species low. However, biodiversity in such stressed but uncompetitive environments may be special.

Human preferences for garden plants are also a potential influence on the composition of wall vegetation. Known to disperse from their planned location, the aptly named garden escapees are an ever present seed source. Since many gardens are surrounded by walls it can be expected garden escapees will be observed on walls from time to time.

The higher average abundance on basalt and granite walls in Christchurch is a result of building methods used. Concrete walls have in general a smooth surface and are jointed with mortar when concrete 'bricks' were used. The hard building material and precise workmanship leaves very little room for successful vegetative establishment. Many of such walls encountered in both study areas, although sometimes including retaining walls, carried little vegetation. Basalt and granite walls encountered in general were not jointed by mortar but merely stacked, often in such a manner as to retain soil. The coarse and open structures of such walls provide ample opportunity for the successful establishment of vegetation. It was somewhat surprising that abundant vegetation was not encountered more often in these cases but is understandable when frequent spraying and cleansing is carried out.

Several authors have noted the similarities between walls and cliff faces or deserts. In addition walls represent relatively recent habitats, especially in New Zealand, which often resembles frequently/recently disturbed waste lands. The factors that prolong these 'wasteland' conditions are the modern building materials that slow weathering processes needed for the establishment of vegetation, but also frequent management practices. As such, the wall habitat resembles a disturbed natural habitat and could be said to be continuously open for colonization by whatever seeds reach the wall. This also explains why the majority of the species observed are ruderal/colonizing species. Low competition pressure provides an opportunity for many seeds to germinate when conditions are sufficiently favourable. However, harsh environmental conditions will allow only a select few to persist. Therefore, at any one time a relatively high number of species can be recorded growing on walls though temporal studies might prove that only a few species persist over time. A better insight into vegetation dynamics surely will achieved by a long term study, including the effect of seasonality.

The predominance of exotic plant species encountered growing on walls in Christchurch and Dunedin was expected. Anthropogenic sources and historic activities virtually ensure the depression of native species in urban environments generally. The main factors are elimination of seed sources, young age, less jointed and rocky wall substrates and the frequent cleaning and sterilising. Although walls are regarded as biotopes exhibiting low levels of competition there can be competition for sparse receptive surfaces and if propagules of exotic species are ubiquitous and faster to germinate then they will capture the available joints.

In their study on the re-emergence of indigenous forests in Christchurch STEWART & al. 2004 found indications that "more sensitive, less intrusive management" in combination with indigenous seed sources allowed for the regeneration of indigenous species. In addition to management practices, environmental factors appeared to be determining the successful establishment of urban wall vegetation in the study areas. To achieve a more diverse urban wall vegetation (in a relatively short period of time), both accessibility and habitat conditions need attention. Accessibility concerns the proximity of indigenous seed sources to a wall. If no such seed sources are present, native species will consequently fail to appear. When indigenous seed sources are present but suitable conditions for vegetative establishment on urban walls are lacking, no wall vegetation can develop at all.

Before pursuing a detailed outline of how native urban wall vegetation might be achieved, benefits and disadvantages should be identified and investigated. Examples of technological (e.g. climate control of buildings) and health benefits (e.g. reduced hospitalization time and less need of pain medications for postoperative patients) are many. In addition to the health benefits of nature contact, vegetation may filter and trap atmospheric pollutants improving the urban air quality. The relevance is emphasised by the relation of mortality rates and levels of particulate matter (PM10) in the atmosphere (HALES & al. 2000). Spatial distribution patterns of lichens observed in Christchurch may indicate poor air quality in and south-west of the city centre, presumably due to elevated levels of emissions in this densely built up part of the city. The potential of vegetation to improve air quality in the urban area can have significant benefits for public health, and a detailed investigation to quantify such benefits could prove rewarding.

Technological benefits include climate control of buildings, which ultimately reduce emissions and associated expenses. Green roofs presumably provide benefits similar to vegetation on urban walls. The benefits of green roofs have been extensively studied in Toronto (Canada) and include monetary savings on storm water and sewage overflow management, air quality, energy use of buildings, and urban heat island effect (BANTING & al. 2005, IGNATIEVA & al. 2008). A similar city wide study could quantify such benefits for urban wall vegetation.

Enhanced biological diversity as a result of urban (wall) vegetation has more far reaching implications than 'just' enhanced biodiversity. Several authors (e.g. PYLE 2003, MILLER 2005) have described the concept of the 'extinction of experience' which results from loss of contact with nature and consequent alienation. PYLE 2003 and MEURK & SWAFFIELD 2000 predict that reduced contact with dwindling biodiversity results in a cycle of disaffection, degradation and separation from nature. ELHORST & al. 1999 studied the affinity of Singaporean urban youths for nature and found little interest or affinity for nature. This was ascribed to growing up in a highly urbanized area with myriad alternative recreational options and over protective (biophobic) parents. Based on their study, ELHORST & al. 1999 assert that reduced interaction between young urbanites and nature will desensitise them from the value of nature. Childhood bonding through exploring the natural environment in play is deemed essential in the development of caring behaviour for the environment (PYLE 2003, LOUV 2005). Re-introduction of natural elements into an urbanized environment potentially contributes to the development of bio-phily, which in turn will provide a basis for the support and maintenance of biological diversity in urban areas. In this sense, the downward spiral of 'extinction of experience' can be reversed.

The benefits briefly described, although incomplete and in need of further research, do indicate the significance of urban vegetation. Vegetation on urban walls has great potential, if only due to the large surface area comprising urban walls. Consider the benefits of green roofs as described by BANTING & al. 2005, each roof in general is accompanied by four external walls; the potential is apparent. Although urban ecosystems are often viewed as 'unnatural', characteristics of the built environment replicate 'natural' rock faces on which rock outcrop species naturally occur (MEURK & SWAFFIELD 2007). LUNDHOLM & MARLIN 2006 showed the high proportions of species from rock habitats in urban areas, whereas grassland and flood-plain species occurred in lower proportions. Although colonization might be slow due to unfavourable conditions and the lack of nearby (indigenous) seed sources, a combination of time and appropriate management strategies allow development of desirable vegetation on the urban 'rock faces'.

The colonization process can be artificially accelerated by enhancing dispersal, improving accessibility and habitat conditions. In urban development areas this can be achieved by alterations of the wall structure for example. Wall vegetation or green walls is particularly attractive as a natural feature in densely built up areas (IGNATIEVA & al. 2008). Different from parks or green strips, wall vegetation takes virtually no additional space, a significant consideration in areas with intensive land use and associated high prices. In New Zealand the successful establishment of native species in the urban area is essential. Based on the high proportion of exotic species observed on urban walls during this study, it can be assumed that exotics will at least initially prevail in the urban environment. Further research is needed to investigate how the change of a majority of exotic to a majority native species can be achieved. Restoring native seed sources in the urban area could be a management tool, as this seemed to have been favourable for the re-emergence of indigenous forests in Christchurch (STEWART & al. 2004). Another possible research thread is whether increased public awareness of the potential value of wall vegetation and knowledge about its detrimental effects can contribute to enhanced biodiversity on urban walls.

6. Aknowledgements

We would like to thank Prof. Dr. G. OROS (Hungarian Academy of Sciences) for assistance with the ordination analyses, Prof. Dr. W. HOLZNER (BOKU, Vienna) for expert supervision, Prof. Dr. Maria IGNATIEVA and Mr Hamish MAULE (Lincoln University) for species identification, and Ms Julia KÖMIVES for assistance with data collection. This study was conducted as partial fulfilment for a Masters degree in Natural Resources Management and Ecological Engineering, an international degree based on collaboration between Lincoln University (New Zealand), The University of Natural Resources and Applied Life Sciences (BOKU, Austria) and the Czech University of Life Sciences.)

7. References

ALLAN H. H. 1982. Flora of New Zealand, 1. – Government Printer, Wellington, New Zealand.

BANTING D., DOSHI H., LI J., MISSIOS P., AU A., CURRIE B. A. & VERRATI M. 2005. Report on the environmental benefits and costs of green roof technology for the city of Toronto. – Toronto, Ryerson University.

BRANDES D. 1992. Flora und Vegetation von Stadtmauern. – Tuexenia 12: 315–339.

BREUSTE J. H. 2004. Decision making, planning and design for the conservation of indigenous vegetation within urban development. – Landscape and Urban Planning 68: 439–452.

CANEVA G., PACINI A., CELESTI GRAPOW L. & CESCHIN S. 2003. The Colossuem's use and state of abandonment as analysed through its flora. – International Biodeterioration & Biodegradation 51: 211–219.

CHRISTCHURCH CITY COUNCIL 2000. Christchurch City Update 2000. – Christchurch.

COLLINS J. P., KINZIG A., GRIMM N. B., FAGAN W. F., HOPE D., WU J. & BORER E. 2000. A new urban ecology. – American Scientist 88(5): 416.

DARLINGTON A. 1981. Ecology of walls. – London, Heinemann Educational.

DUCHOSLAV M. 2002. Flora and vegetation of stony walls in East Bohemia (Czech Republic). – Preslia 74: 1–25.

DUNEDIN CITY COUNCIL 2003. Monitoring natural areas. – Dunedin.

DUNN R. R., GAVIN M. C., SANCHEZ M. C., & SOLOMON J. N. 2006. The pigeon paradox: Dependence of global conservation on nature. – Conservation Biology 20(6): 1814–1816.

EDGAR E. & CONNOR H. 2000. Flora of New Zealand, 5. – Manaaki Whenua Press, Lincoln.

ELHORST P., OOSTERHAVEN J., SIJTSMA F., & TELDER D. 1999. The construction and experience of nature: perspectives of urban youths. – Tijdschrift voor economische en sociale Geografie 90(1): 3–16.

FORSTNER W. 1983. Ruderale Vegetation in Ost-Österreich. Teil 1. – Wissenschaftliche Mitteilungen aus dem niederösterreichischen Landesmuseum 2: 19–133.

HALES S., SALMOND C., TOWN G. I., KJELLSTROM T., & WOODWARD A. 2000. Daily mortality in relation to weather and air pollution in Christchurch, New Zealand. – Australian and New Zealand Journal of Public Health 24(1): 89–91.

HEALY A. J. & EDGAR E. 1980. Flora of New Zealand, 3. – Government Printer, Wellington, New Zealand.

HILL D., TUCKER G., FASHAM M., SHREWRY M. & SHAW P. 2005. Handbook of biodiversity methods. Survey, evaluation and monitoring. – Cambridge, Cambridge University Press.

HORNE B., STEWART G., MEURK C., IGNATIEVA M. & BRADDICK T. 2005. The origin and weed status of plants in Christchurch lawns. – Canterbury botanical Society Journal 39: 5–12.

IGNATIEVA M., MEURK C., VAN ROON M., SIMCOCK R. & STEWART G. 2008. How to put urban nature into our neighbourhoods: Application of Low Impact Urban Design and Development (LIUDD) principles with a biodiversity focus, for New Zealand developers and landowners. - Landcare Research Science Series 35: 52p.

LISCI M. & PACINI E. 1993. Plants growing on the walls of Italian towns 1.Sites and distribution. – Phyton (Horn, Austria) 33(1): 15–26.

LOUV R. 2005. Lost child in the woods – saving our children from nature-deficit dicorder. – NC, Chapel Hill.

LUNDHOLM J. T. & MARLIN A. 2006. Habitat origins and microhabitat preferences of urban plant species. – Urban Ecosystems 9(3): 139–159.

MCKINNEY M. L. 2002. Urbanization, biodiversity, and conservation. – BioScience 52(10): 883–890.

MEURK C. D. & NORTON D. A. 1988. A conservation blueprint for Christchurch. – Canterbury botanical Society Journal 22: 3–15.

MEURK C. D. 2005. Cities are cultural and ecological keys to biodiverse futures. – In: DAWSON M. I. (ed.), Greening the city: bringing biodiversity back into the urban environment: proceedings of a conference held by the Royal New Zealand Institute of Horticulture in Christchurch, 21–24 October 2003. pp 301–310. – Royal New Zealand Institute of Horticulture, Lincoln University.

MEURK C. D. & SWAFFIELD S. R. 2000. A landscape ecological framework for indigenous regeneration in rural New Zealand – Aotearoa. – Landscape and Urban Planning 50: 129–144.

MEURK C. D. & SWAFFIELD S. R. 2007. Cities as complex landscapes: biodiversity opportunities, landscape configurations and design directions. – New Zealand Garden Journal 10: 10–20.

MILLER J. R. 2005. Biodiversity conservation and the extinction of experience. – Trends in Ecology and Evolution 20(8): 430–434.

MOORE L. B. & EDGAR E. 1970. Flora of New Zealand, 2. – Government Printer, Wellington, New Zealand.

NIWA, N. I. o. W. A. R. L. 2007. Retrieved 24-10-2007, from http://www.niwascience.-co.nz/edu/resources/climate.

PAVLOVA D. & TONKOV D. S. 2005. The wall flora of the Nebet Tepe Architectural Reserve in the city of Plovdiv (Bulgaria). – Acta botanica croatica 64(2): 357–368.

PYLE R. M. 2003. Nature matrix: reconnecting people and nature. – Oryx 37(2): 206–214.

RISHBETH J. 1948. The flora of Cambridge walls. – The Journal of Ecology 36(1): 136–148.

SAVARD J. L., CLERGEAU P., & MENNECHEZ G. 2000. Biodiversity concepts and urban ecosystems. – Landscape and Urban Planning 48: 131–142.

SEGAL S. 1969. Ecological notes on wall vegetation. – Amsterdam, Dr. W. Junk N.V.

SHLENS J. 2003. A tutorial on principal component analysis. www.cs.princeton.edu/picasso/mats/PCA-Tutorial-Institution_ip.pdf

STATISTICS NEW ZEALAND. 2006. 2006 Census. Retrieved 5-12-2007.

STEWART G. H., IGNATIEVA M. E., MEURK C. D. & EARL R. D. 2004. The re-emergence of indigenous forest in an urban environment, Christchurch, New Zealand. – Urban Forestry and Urban Greening 2: 149–158.

SUKOPP H. 2002. On the early history of urban ecology in Europe. – Preslia 74: 373–393.

TURNER W. R., NAKAMURA T., & DINETTI M. 2004. Global urbanization and the separation of humans from nature. – Bioscience 54(6): 585–590.

UN, U. N. D. o. E. a. S. A. P. D. 2006. World Urbanization Prospects: The 2005 Revision. – New York, United Nations.

WEBB C. J., SYKES W. R. & GARNOCK-JONES P. J. 1988. Flora of New Zealand, 4. – Government Printer, Wellington, New Zealand.

WOODELL S. 1979. The flora of walls and pavings. – In: LAURIE I.C. (ed.), Nature in cities, p. 135–157. – Chichester, Wiley.

WOODELL S. & ROSSITER J. 1959. The flora of Durham walls. – Proceedings of the botanical Society of the British Isles 3: 257–273.

ZERBE S., MAURER U., SCHMITZ S. & SUKOPP H. 2003. Biodiversity in Berlin and its potential for nature conservation. – Landscape and Urban Planning 62: 139–148.

Zeitschrift/Journal: Phyton, Annales Rei Botanicae, Horn

Jahr/Year: 2008

Band/Volume: 48_1

Autor(en)/Author(s): De Neef Diederik, Stewart Glenn H., Meurk Colin D.

Artikel/Article: Urban Biotopes of Aotearoa New Zealand (URBANZ) (3): Spontaneous Urban Wall Vegetation in Christchurch and Dunedin. 133-154