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ECOLOGICAL SIGNIFICANCE OF MASONRY REVETMENTS IN PLANT BIODIVERSITY

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ABSTRACT: The objective of this research is to evaluate the importance of vegetation of retaining walls made of natural stones (i.e., masonry revetment) in plant biodiversity. In this paper, plant compositions and the characteristics of masonry revetments were surveyed in terraced fields in Toho Village, southern Japan. In total, 43 families and 88 species were recorded in the spaces of the masonry revetments. Of these 88 species, 68 (77.3%) were herbaceous, excluding 13 (14.8%) ferns, and 7 (8.0%) species were woody plants. Native species accounted for 69 (78.4%) of the 88 species. Furthermore, numerous species not found in the horizontal environments around the terraced fields were also seen in the spaces of the masonry revetments. From these results, the authors consider that masonry revetments provide a habitat for plants and therefore contribute toward the conservation of plant biodiversity on a local scale.

Keywords: Biodiversity, Natural stone, Retaining wall, Terraced field, Vegetation

1. INTRODUCTION

Infrastructure elements such as roads, ports, bridges, power stations, and so forth, are fundamental structures and services that are necessary for supporting today's society. However, a large number of cut slopes and embankments, which accompany the introduction of infra-structure, have especially emerged in Japan, because forests account for the majority of the total land area of Japan (approx. 69%, excluding land submerged in water) [4]. Therefore, to prevent failure and erosion of cut slopes and embankments, revetment techniques have been rapidly developed and introduced. Some examples of these techniques are mortar sprayings, frame construc-tions, and precast segments including concrete blocks (Fig. 1; i-iv).

Since these structures often do not harmonize with their surroundings, a bio-engineering technique (planting and/or seeding for slope protection) has been actively applied over the last several decades, especially in Japan [22], to complement or enhance the peripheral scenery. The bio-engineering technique is also expected to ease global warming and reduce costs in other countries [8]. However, in a few cases, application of a bio-engineering technique is not suitable for protecting some slopes, e.g., those in extremely soft ground or on very steep land. At these places, retaining walls using lumber, natural stones and some other revetment material with less brightness and saturation, which can blend into their surroundings (Fig. 1; v and vi), have recently been highly recommended in Japan [9].

In retaining walls using natural stones (hereafter referred to as "masonry revetments"), many narrow spaces appear between stones, and some plants, animals, and insects frequently colonize the spaces (Fig. 1; v and vii-ix). Among the colonizers, plants are generally considered as the major cause of collapse of masonry revetments and so become a target for removal.

As an alternative, the objective of this paper is to evaluate the importance of masonry revetment vegetation in plant biodiversity. In this study, therefore, plant compositions and the characteristics of masonry revetments were surveyed in a cluster of terraced fields. We examined a large number of masonry revetments under various different land uses in the same area.

2. MATERIALS AND METHODS

2.1 Study Site

The cluster of terraced fields used in this research is located at the Take section of Toho Village in Fukuoka Prefecture, Japan (Fig. 2). The terraced fields, which are at an altitude of 280 to 420 m [21], are surrounded by artificial forests that are mostly *Cryptomeria japonica* and *Chamaecy-paris obtuse*. The terraced fields are mainly used for rice although they have quickly changed into abandoned fields or fields for vegetables, grains, or housing in recent years. Nearly all of the slopes of

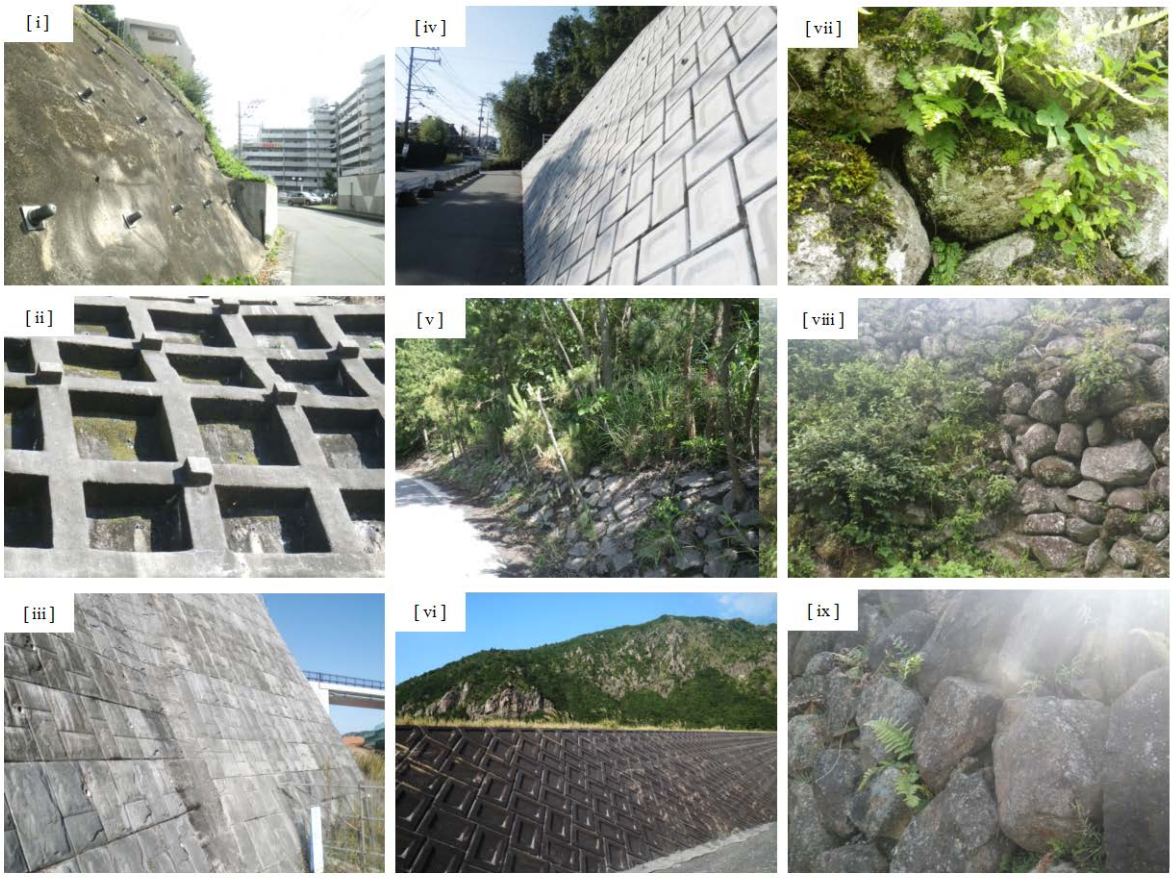

Fig. 1 Some examples of revetment techniques
[i] mortar spraying (with rock bolts); [ii] frame construction; [iii] precast segments; [iv] concrete blocks; [v] natural stones; [vi] concrete blocks with less brightness and saturation; [v], [vii], [viii] and [ix] masonry revetments and some plants colonizing the spaces between stones

the terraced fields are protected by masonry revetments with a southeastern aspect [21]. The dimensions of the revetments are approximately as follows: height 1 to 10 m, width 10 to 25 m, and inclination angle 70° to 80°. Also, the masonry revetments are the dry type [10], and on average they have 22 stones and a porosity of 7.5% per square meter.

According to data of the Automated Meteorological Data Acquisition System (AMEDAS) from 2004 to 2013, this surveyed area lies in the warm-temperature zone: the values of Kira's Warmth Index [12] range from 125.8 to 138.6 and the annual precipitation is 1,265 to 2,499 mm.

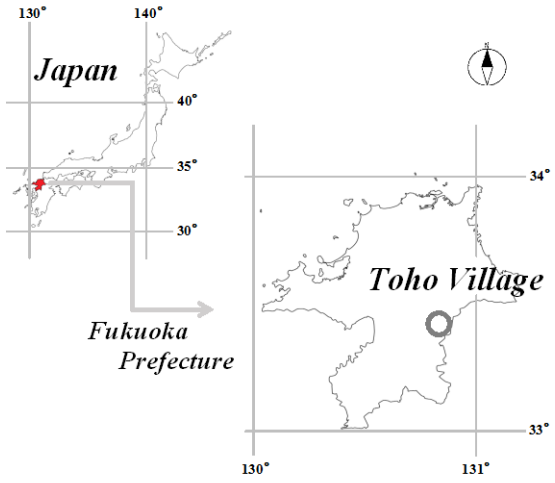

Fig. 2 Location of the study site

2.2 Species Composition and Characteristics

Surveying of vegetation in the spaces between stones of masonry revetments was conducted from mid-September to early October, 2013. We examined 55 masonry revetments at random, using a survey quadrat located on vertical surface of the revetment at a height of 130 cm. The size of a quadrat was 100 cm long and 100 cm wide. The species composing the vegetation were recorded according to the methodology of the Braun-Blanquet cover-abundance scale [2]. In addition,

the land-use type of each masonry revetment was classified as a paddy field, a dry field, an abandoned field, or "others", which included housing, parking lots, etc.

The plant nomenclature used in this paper followed that of Miyawaki et al. (1994), Baba (1999), and Shimizu (2003). All the recorded species were categorized by life form (dormancy form, disseminule form, radicoid form, and growth form). The life forms were based on descriptions by Raunkiaer (1934) and Numata (1990). The invasive status (native or non-native) was also categorized based on published literature [1], [13], [18].

To compare the vegetation of the masonry revetments with that of the surroundings, surveying of the vegetation was also conducted in 54 horizontal environments around the terraced fields, such as walkways between paddy fields, abandoned fields, and parking lots.

2.3 Data Analysis

The Braun-Blanquet cover-abundance scale (r, +, I, II, III, IV, and V) was transformed as follows: r and +, 0.1%; I, 5.0%; II, 17.5%; III, 37.5%; IV, 62.5%, and V, 87.5%. Then, in Eq. (1), the summed dominance ratio (SDR) of each species [15] was calculated:

$$SDR = (F' + C')/2 \quad (1)$$

where F' and C' are the ratio of frequency and cover of each species to the numbers of the most abundant species, respectively.

To find out whether the characteristics of vegetation in the spaces of the masonry revetments were different by land-use type of the terraced fields, we conducted a Shapiro-Wilk test under the null hypothesis that the vegetation characteristics of the masonry revetments were equivalent across all land-use types [3], [23]. The vegetation characteristics employed were the following: total number of species, average number of species, Shannon-Wiener's diversity index (H'), and percentages of native, herbaceous, and ferny species.

3. RESULTS

In total, 43 families and 88 species were obtained in this survey. Native species accounted for 69 (78.4%) of the 88 species observed in the spaces of the masonry revetments surveyed. Moreover, of the 88 species, 68 (77.3%) species were herbaceous, excluding 13 (14.8%) ferns, and 7 (8.0%) species were woody plants. Of the 68 herbaceous species, 37 (54.4%) were ephemeral (annual and biennial) plants and 31 (45.6%) were perennials. Of the 43 families obtained in this survey, the most abundant families were Asteraceae (19/88 species) followed by Poaceae (9/88 species) and Leguminosae (4/88 species). Appendix 1 lists the plant compositions, land-use types, and life forms.

The species common to all land-use types (7/88 species) were *Acalypha australis*, *Boehmeria nipononivea*, *Equisetum arvence*, *Pteris* × *sefuricola*, *Stenactis annuus*, *Trachelospermum asiaticum*, and *Youngia japonica*. Conversely, species that emerged only in one specific land-use type were also observed. In only paddy fields, 15 species were observed, e.g., *Eclipta alba*, *Houttuynia cordata*, *Ixeris stolonifera*, *Lobelia chinensis*, *Osmunda japonica*, and *Vigna angularis*. In only dry fields, 6 species were observed: *Akebia trifoliata*, *Asplenium trichomanes*, *Chenopodium album*, *Gamochaeta coarctata*, *Lilium formosanum*, and *Sonchus oleraceus*. In only abandoned fields, 16 species were observed, e.g., *Cosmos sulphureus*, *Cryptomeria japonica*, *Miscanthus sinensis*, *Persicaria lapathifolia*, *Ranunculus silerifolius*, and *Rhynchosia volubilis*. In only the other fields for housing, parking lots, etc., 6 species were observed: *Arthraxon hispidus*, *Cosmos bipinnatus*, *Dioscorea polystachya*, *Echinacea purpurea*, *Lampranthus spectabilis*, and *Trisetum bifidum*.

Meanwhile, a total of 40 families containing 101 species were observed in the horizontal environments around the terraced fields. It should be especially noted that numerous species not recorded in the horizontal environments were obtained from vegetation of the masonry revetments (48/88 species; 54.5%).

From the species found in the masonry revetments only, many perennials (H and Ch; 39.6%) were obtained, as well as ephemeral plants (Th and Th(w); 35.4%). The dominant dispersal modes were anemochory (D1; 43.8%) or barochory (D4; 39.6%). In the radicoid and growth forms, the majority of each form was "R5 (56.3%)" and "e (39.6%)", respectively. This implies that vegetation of the masonry revetments was spread primarily by seed.

On the other hand, no significant differences were found in the vegetation characteristics of the masonry revetments across the land-use types of the terraced fields ($P > 0.05$) (Table 1).

4. DISCUSSION

Numerous studies on vegetation colonizing hard surfaces such as pavement, rubble, roofs,

Table 1 Vegetation characteristics of masonry revetment in each land-use type

Land-use types	Vegetation characteristics						
	Number of survey plots	Total number of species	Average number of species	Shannon-Wiener's diversity index (*H'*)	Native species,%	Herbaceous† species, %	Ferny species, %
Paddy fields	29	55	6.2	5.260	83.6	72.7	21.8
Dry fields	8	35	6.6	4.917	82.9	65.7	25.7
Abandoned fields	14	53	8.4	5.395	81.1	75.5	15.1
Others	4	22	8.3	4.166	72.7	77.3	18.2
P-value	-	0.405^{ns}	0.164^{ns}	0.404^{ns}	0.103^{ns}	0.500^{ns}	0.954^{ns}

† Except for ferns. Woody species, %: 100 - [herbaceous species, %] - [ferny species, %]. ns $P > 0.05$: not significant using Shapiro-Wilk test

ruins, building walls, and stone walls (masonry revetments) have been conducted, and it is widely understood that these surfaces are sufficiently able to support various taxa [5], [10], [11], [19], [20]. However, those studies are overwhelmingly concentrated in Europe [10], whereas information originating in other countries and regions regarding vegetation of hard surfaces, including masonry revetments, is lacking despite the importance of plant habitats.

In this study, 43 families and 88 species including 69 (78.4%) natives were observed between stones of the masonry revetments (Appendix 1). Our results are not surprising, because even hard surfaces such as cracks in pavement and mortared walls provide good opportunities for plants to colonize [10], [19].

In environments with hard surfaces, ephemeral annuals or short-lived taxa (due to disturbance by human activities) tend to be dominant instead of perennials including woody plants [5], [7], [11]. However, many perennial herbs (45.6%; excluding ferns) and even woody plants (8.0%) were obtained in this survey, as well as ephemeral (annual and biennial) plants. Additionally, a large number of species not observed in the horizontal environments around the terraced fields were recorded.

On a local scale, therefore, we consider that the masonry revetments play an important ecological role in providing habitat for plants and in so doing, contribute toward the conservation of plant biodiversity. Incidentally, of the plants colonizing the masonry revetments, the main ecological types were species, mainly Asteraceae and Poaceae, propagating by seed with wind dispersal (D1; anemochory), or gravity dispersal (D4; barochory) mechanisms. These observations are in total agreement with previous reports on hard surface vegetation [6], [7], [19].

On the other hand, vegetation characteristics such as the number of species, the diversity index (*H'*), and the percentage of native species in the masonry revetments were not affected by the land-use types of terraced fields (Table 1). However, the plant composition of each land-use type was highly distinctive. Common species among land-use types could be defined as typical species in the masonry revetment vegetation, for example, *Acalypha australis*, *Equisetum arvence*, *Trachelospermum asiaticum*, and *Youngia japonica*. Conversely, the species observed only in a certain land-use type would be regarded as a peculiar plant, e.g., *Lampranthus spectabilis*, *Lilium formosanum*, *Oenanthe javanica*, and *Ranunculus silerifolius*, that is heavily dependent on its environment.

Moisture availability is the most important environmental factor for the development of hard surface vegetation [10], [16], [20]. That is, differences of moisture conditions in the masonry revetments, which accompany land-use change, would lead to varied plant composition. While infrastructure elements have long been mentioned as a force to reduce vegetation coverage, the masonry revetments installed in various locations with different moisture conditions could lead to plant biodiversity on a local scale.

In general, plants are considered to be the major cause of collapse of masonry revetments. Nevertheless, it is evident that masonry revetments play a significant role, not only in protecting slopes and embankments, but also in maintaining or ameliorating plant biodiversity on a local scale. Therefore, it would be a challenge to be tackled in

the future to overcome or moderate a trade-off between plant biodiversity and maintaining masonry revetments.

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Appendix 1 Species recorded in this survey, and they were listed according to plant composition of each land-use type

Species	Family	Land-use types				Life form				Occurrence frequency (%)
		Paddy fields (*n* =29)	Dry fields (*n* =8)	Abandoned fields (*n* =14)	Others (*n* =4)	Dormancy	Disseminule	Radicoid	Growth	
Acalypha australis †, γ	Euphorbiaceae	II	II	+	III	Th	D3	R5	e	16.4
Boehmeria nipononivea †, §	Urticaceae	III	III	III	II	Ch	D4	R3	e	41.8
Equisetum arvence ‡	Equisetaceae	I	II	I	II	G	D1	R1	e	16.4
Pteris × *sefuricola* ‡	Pteridaceae	II	III	I	II	H	D1	R3	e	30.9
Stenactis annuus †, #, γ	Asteraceae	III	II	III	I	Th(w)	D1	R5	pr	49.1
Trachelospermum asiaticum ω	Apocynaceae	II	V	IV	V	Ch	D1	R5	l	25.5
Youngia japonica †, γ	Asteraceae	II	I	II	I	Th(w)	D1	R5	ps	25.5
Echinochloa crusgalli †, γ	Poaceae	II				Th	D4	R5	t	3.6
Eclipta alba †, #, γ	Asteraceae	+				Th	D1	R5	e	7.3
Elatostema laetevirens †, §	Urticaceae	II				H	D4	R3	e	1.8
Eleusine indica †, γ	Poaceae	+				Th	D4	R5	t	3.6
Houttuynia cordata †, §	Saururaceae	I				G	D4	R1	e	3.6
Ixeris stolonifera †, §	Asteraceae	r				H	D1	R4	p	1.8
Lobelia chinensis †, §	Campanulaceae	r				H	D4	R3	p	1.8
Mallotus japonicus ω	Euphorbiaceae	r				MM	D2	R5	e	1.8
Oenanthe javanica †, §	Umbelliferae	II				H	D4	R4	e	1.8
Osmunda japonica ‡	Osmundaceae	I				G	D1	R3	t	5.5
Paederia scandens †, §	Rubiaceae	+				Ch	D4	R3	l	3.6
Phyllanthus urinaria †, γ	Euphorbiaceae	r				Th	D3	R5	e	1.8
Sonchus asper †, #, γ	Asteraceae	+				Th(w)	D1	R5	pr	1.8
Vigna angularis †, γ	Leguminosae	III				Th	D3	R5	l	1.8
Viola verecunda †, §	Violaceae	+				H	D3	R3	b	5.5
Akebia trifoliata ω	Lardizabalaceae		I			M	D2	R3	l	1.8
Asplenium trichomanes ‡	Aspleniaceae		I			E	D1	R3	t	1.8
Chenopodium album †, γ	Chenopodiaceae		I			Th	D4	R5	e	1.8
Gamochaeta coarctata †, #, γ	Asteraceae		I			H	D1	R5	b	1.8
Lilium formosanum †, #, §	Liliaceae		I			H	D3	R5	e	1.8
Sonchus oleraceus †, γ	Asteraceae		II			Th(w)	D1	R5	pr	1.8
Amphicarpaea edgeworthii †, γ	Leguminosae			I		Th	D3	R5	l	3.6
Bothriospermum zeylanicum †, γ	Boraginaceae			+		Th	D4	R5	b	1.8
Capillipedium parviflorum †, §	Poaceae			+		Ch	D1	R3	t	1.8
Conyza canadensis †, #, γ	Asteraceae			I		Th(w)	D1	R5	pr	3.6
Cosmos sulphureus †, #, γ	Asteraceae			+		Th	D4	R5	e	1.8
Cryptomeria japonica ω	Taxodiaceae			+		MM	D1	R5	e	1.8
Euchiton japonicus †, §	Asteraceae			+		H	D1	R5	b	1.8
Ixeris japonica †, §	Asteraceae			+		H	D1	R3	ps	1.8
Miscanthus sinensis †, §	Poaceae			I		Ch	D1	R3	t	1.8
Persicaria lapathifolia †, γ	Polygonaceae			+		Th	D4	R5	e	1.8
Ranunculus silerifolius †, §	Ranunculaceae			+		Th(w)	D4	R5	e	1.8
Rhynchosia volubilis †, §	Leguminosae			+		H	D3	R5	l	1.8
Sagina japonica †, γ	Caryophyllaceae			I		Th	D4	R5	b	1.8
Setaria faberi †, γ	Poaceae			+		Th	D4	R5	t	1.8
Stellaria aquatica †, γ	Caryophyllaceae			II		Th(w)	D4	R5	b	5.5
Toxicodendron radicans ω	Anacardiaceae			I		MM	D4	R5	l	1.8
Arthraxon hispidus †, γ	Poaceae				I	Th	D4	R5	t	1.8
Cosmos bipinnatus †, #, γ	Asteraceae				I	Th	D4	R5	e	1.8
Dioscorea polystachya †, #, §	Dioscoreaceae				I	G	D1	R5	l	1.8
Echinacea purpurea †, #, §	Asteraceae				I	Ch	D4	R5	e	1.8
Lampranthus spectabilis †, #, §	Aizoaceae				V	Ch	D4	R5	p	3.6
Trisetum bifidum †, §	Poaceae				II	H	D4	R5	e	3.6

Appendix 1 Continued

Species	Family	Land-use types				Life form				Occurrence frequency (%)
		Paddy fields (*n* =29)	Dry fields (*n* =8)	Abandoned fields (*n* =14)	Others (*n* =4)	Dormancy	Disseminule	Radicoid	Growth	
Lactuca indica †, γ	Asteraceae	r	I	I		Th	D1	R5	pr	7.3
Achyranthes fauriei †, §	Amaranthaceae	II		I	I	H	D2	R3	e	14.5
Artemisia princeps †, §	Asteraceae	+	II	+		Ch	D4	R2	e	5.5
Asplenium sarelii ‡	Aspleniaceae	I	III	II		E	D1	R3	t	21.8
Athyrium niponicum ‡	Woodsiaceae	III	III		III	H	D1	R2	e	23.6
Athyrium vidalii ‡	Woodsiaceae	II	I	I		H	D1	R3	t	12.7
Athyrium wardii ‡	Woodsiaceae	+	II	I		H	D1	R2	e	12.7
Boehmeria spicata ω	Urticaceae		II	I		Ch	D4	R3	e	3.6
Camellia sinensis ω, #	Theaceae	II		IV		MM	D4	R5	e	5.5
Chamaele decumbens †, §	Umbelliferae	r	I	II		G	D4	R5	ps	10.9
Chamaesyce maculata †, #, γ	Euphorbiaceae	+			I	Th	D3	R5	b	5.5
Clinopodium gracile †, §	Labiatae	r		II		H	D4	R5	b	9.1
Commelina communis †, γ	Commelinaceae	II	I	II		Th	D4	R5	b	14.5
Corydalis racemosa †, γ	Papaveraceae	r	II	II		Th(w)	D4	R5	b	9.1
Crassocephalum crepidioides †, #, γ	Asteraceae	+		+		Th	D1	R5	pr	3.6
Cyperus iria †, γ	Cyperaceae	r	I			Th	D4	R5	t	3.6
Deparia conilii ‡	Woodsiaceae	r	II	I		H	D1	R2	e	7.3
Digitaria ciliaris †, γ	Poaceae	III	II	II		Th	D4	R4	t	30.9
Dunbaria villosa †, §	Leguminosae		I	I		H	D3	R3	l	5.5
Fatoua villosa †, γ	Moraceae	r			I	Th	D3	R5	e	3.6
Galinsoga quadriradiata †, #, γ	Asteraceae	I	I	II		Th	D4	R5	e	20.0
Gamochaeta pensylvanica †, #, γ	Asteraceae		I	II		Th(w)	D1	R5	b	7.3
Geranium nepalense †, §	Geraniaceae	+	I	+		H	D3	R5	b	7.3
Glechoma hederacea †, §	Labiatae	+		I		H	D4	R4	p	5.5
Hydrocotyle sibthorpioides †, §	Umbelliferae	r			I	Ch	D4	R4	p	3.6
Impatiens balsamina †, #, γ	Balsaminaceae	II		I		Th	D3	R4	b	5.5
Justicia procumbens †, γ	Acanthaceae	I	I	III		Th	D3	R5	e	21.8
Lemmaphyllum microphyllum ‡	Polypodiaceae	II			II	E	D1	R2	e	5.5
Lepisorus thunbergianus ‡	Polypodiaceae	I	I			E	D1	R3	e	10.9
Lygodium japonicum ‡	Schizaeaceae	I		II		H	D1	R2	l	9.1
Mollugo stricta †, γ	Molluginaceae	r	I			Th	D4	R5	b	3.6
Oxalis corniculata †, §	Oxalidaceae	I		I	I	Ch	D3	R4	p	14.5
Oxalis dillenii †, #, §	Oxalidaceae		II	II		Ch	D3	R4	p	7.3
Setaria viridis †, γ	Poaceae		II	II	I	Th	D4	R5	t	10.9
Stellaria neglecta †, γ	Caryophyllaceae	r		II		Th(w)	D4	R4	b	5.5
Taraxacum officinale †, #, §	Asteraceae	I		+		H	D1	R3	r	7.3
Thelypteris decursivepinnata ‡	Thelypteridaceae	II		+		H	D1	R3	t	5.5
Trichosanthes cucumeroides †, §	Cucurbitaceae	+		II	I	G	D4	R5	l	12.7

In land-use types Roman numerals and other symbols for each species indicate SDR classes, defined as follows: r, under 5%; +, under 10%; I, under 20%; II, under 40%; III, under 60%; IV, under 80%, and V, above 80%. †, herbaceous species (excluding ferns); ‡, ferny species; ω, woody species; #, non-native species; γ, ephemeral (annual and biennial) herbs, and §, perennial herbs. Highlight: species observed in masonry revetment only

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