2018 *Green Roofs and Urban Biodiversity* Special Issue No. 1:16–38
*URBAN NATURALIST*

# Developing Biodiverse Green Roofs for Japan: Arthropod and Colonizer Plant Diversity on Harappa and Biotope Roofs

Ayako Nagase[1,*], Yoriyuki Yamada[2], Tadataka Aoki[2], and Masashi Nomura[3]

**Abstract -** Urban biodiversity is an important ecological goal that drives green-roof installation. We studied 2 kinds of green roofs designed to optimize biodiversity benefits: the Harappa (extensive) roof and the Biotope (intensive) roof. The Harappa roof mimics vacant-lot vegetation. It is relatively inexpensive, is made from recycled materials, and features community participation in the processes of design, construction, and maintenance. The Biotope roof includes mainly native and host plant species for arthropods, as well as water features and stones to create a wide range of habitats. This study is the first to showcase the Harappa roof and to compare biodiversity on Harappa and Biotope roofs. Arthropod species richness was significantly greater on the Biotope roof. The Harappa roof had dynamic seasonal changes in vegetation and mainly provided habitats for grassland fauna. In contrast, the Biotope roof provided stable habitats for various arthropods. Herein, we outline a set of testable hypotheses for future comparison of these different types of green roofs aimed at supporting urban biodiversity.

## Introduction

Rapid urban growth and associated anthropogenic environmental change have been identified as major threats to biodiversity at a global scale (Grimm et al. 2008, Güneralp and Seto 2013). Green roofs can partially compensate for the loss of green areas by replacing impervious rooftop surfaces and thus, contribute to urban biodiversity (Brenneisen 2006). Green roofs can support arthropods (Hwang and Yue 2015, Kadas 2006, MacIvor and Lundholm 2011, MacIvor et al. 2015, Madre et al. 2013, Nagase and Nomura 2014), including both common and rare species (Brenneisen 2006, Grant 2006).

In order to optimize biodiversity benefits, biodiverse roofs in Switzerland and the UK have focused on particular species of concern; e.g., *Phoenicurus ochruros* Gmelin (Black Redstart), which relies on old vacant lots and brownfield sites (Gedge 2003). Biodiverse roofs are designed to recreate such habitats by using urban substrates such as brick rubble, crushed concrete, sands and gravels, and minimal vegetation. Some cities (e.g., Basel, Switzerland; Toronto, Canada; and London, UK) have green-roof policies that include biodiversity objectives (Williams et al. 2014). Furthermore, a number of different roof styles have emerged to target specific taxa and to mimic local habitats (Lundholm 2006).

[1]College of Liberal Arts and Sciences, Chiba University, Chiba, Japan. [2]Green Infrastructure Group, Kajima Corporation, Tokyo, Japan. [3]Graduate School of Horticulture, Chiba University, Chiba, Japan. [*]Corresponding author - anagase@chiba-u.jp.

Manuscript Editor: Sylvio Codella

Although the number of biodiverse roofs is increasing in some European countries, few examples exist in Japan (Ishimatsu and Ito 2013, Yamada et al. 2013), where there seem to be several cultural and political barriers. First, in the UK, a brownfield site is defined as "previously developed land" that has the potential for repurposing. In contrast, a brownfield site in the USA refers to industrial land that has been abandoned and is contaminated with low levels of hazardous waste and pollutants (Gray 2015). Brownfield sites also have a negative connotation in Japan; therefore, it has been difficult to promote the concept there.

Second, the Japanese perception is that green roofs should be kept green; therefore *Sedum* spp. (stonecrops) are frequently used. However, it is very difficult to keep such plantings in good condition in Japan without irrigation and intensive maintenance (MLITT 2009).

Finally, green-roof regulations vary among cities, and many local Japanese authorities encourage the installment of intensive (thick substrate; require both regular maintenance and an irrigation system) rather than extensive green roofs (thin substrate; require little maintenance/irrigation). Subsidies to install green roofs are often contingent on selecting the intensive option (Organization for Landscape and Urban Infrastructure 2016). In Japan, 54% of local jurisdictions cannot provide subsidies for biodiverse roofs and a further 33% have reduced subsidies for biodiverse roofs that do not fulfill depth and/or irrigation requirements (Yamada et al. 2013).

In Japan, the number of green roofs has increased, with at least 413 ha installed between 2001 and 2014 (MLITT 2014). Methods to construct inexpensive, lightweight, extensive green roofs must be developed in order to facilitate further installation and retro-fitting. Although intensive roofs may provide habitats that promote biodiversity, the potential advantages of extensive roofs suggest that further investigations are warranted.

Our research group has adapted European extensive green-roof design to Japanese culture. We developed a region-specific design: the Harappa Roof. "Harappa" is a Japanese word that describes vacant lots or open fields, including grasslands frequently found in residential areas (Fig. 1). These lots are important play areas for children and have been valuable habitats for grassland fauna since the Showa era (1926–1989; Shuowen 2006). We developed the Harappa style to sidestep the negative image of brownfield. Although the community structure of brownfields and Harappa is similar, the public perception is quite different. Many people have childhood experiences playing in Harappa, and thus there is nostalgia for such sites in many Japanese cities (Nagase et al. 2015).

To promote biodiversity benefits, the Biotope Roof has also been developed and installed in Japan. Biotope roofs are intensive roofs planted with various species, including native trees and shrubs, which serve as hosts and nectar sources for arthropods. These roofs can also include water features, stones, and other structural elements, to create diverse habitats. They require careful maintenance to avoid colonization by invasive plant species (Nagase and Nomura 2014).

In this paper we introduce the Harappa roof and encourage green-roof practicioners outside Japan to explore its local possibilities (Lundholm 2006). We present empirical data on differences in arthropod diversity between the extensive Harappa and the intensive Biotope designs. We use this comparison to generate hypotheses for further testing. Previous studies in Europe have compared arthropod taxa on different types of extensive green roofs (e.g., Baumann 2006, Brenneisen 2006, Grant, 2006, Kadas 2006), but little research has compared extensive and intensive roofs (e.g., Coffman and Davis 2005, Coffman and Waite 2010). Our ultimate goal is to increase the number of green roofs in Japan that will support biodiversity.

## Field-site Description

We installed a Biotope roof and a Harappa roof on the Nishichiba campus of Chiba University, Chiba City, Chiba Prefecture, Japan (Table 1). Chiba has a humid, subtropical climate, with hot summers and mild winters (Fig. 2). We installed the Harappa roof (180 $m^2$) during winter 2012 on a 4-story building (Fig. 3), where it received full sunlight throughout the day. We used recycled materials whenever possible (at Harappa sites, previous construction materials, such as large pipes, tend to remain in situ; these materials are then repurposed for children's imaginative play). Therefore, we collected recycled materials from the surrounding neighborhoods to replicate Harappa conditions and to be more environmentally friendly than conventional green roofs. To construct the roof we placed a drainage layer, substrate material, and vegetation. Materials used

Figure 1. Typical Harappa roof in an urban area.

included straw from replacement of thatched roofs, bamboo, old clothes (fleece), plastic bottle caps, crushed concrete, and roof tiles. The Harrapa roof substrates also included topsoil with vegetation and seeds collected from ground-level Harappa habitat and spread over the crushed concrete and roof tiles. The substrate depth varied from 5 cm to 20 cm.

Table 1. Summary of Harappa roof and biotope roof at Chiba University. Initial costs include materials, shipping, labor, and facilities such as irrigation systems for green roofs.

| Spec. | Harappa roof (extensive) | Biotope roof (intensive) |
|---|---|---|
| Initial cost | 8000 yen/m$^2$ | 40,000 yen/m$^2$ |
| Depth of substrate | 5–20 cm | 50 cm |
| Drainage layer and moisture retention mat | Straw, bamboo, old clothes (fleece), caps of PET bottles | Commercial plastic drainage layer and moisture retention mat |
| Substrate | Crushed brick, concrete, natural soil | Commercial green roof substrate |
| Plants | From neighborhood: transplanting, spontaneous vegetation | From nursery: mainly native plants including trees, shrubs and forbs; spontaneous vegetation |
| Irrigation system | No irrigation | Drip irrigation system |
| Maintenance | Little maintenance | Once a month regular maintenance |
| Water feature | Temporary pond | Circulated pond |
| Structures for biodiversity | Temporary pond, piles of stones, empty flower pots, dead branches | Pond, piles of stones |
| User involvement | Design, collecting materials, construction, survey | Survey |

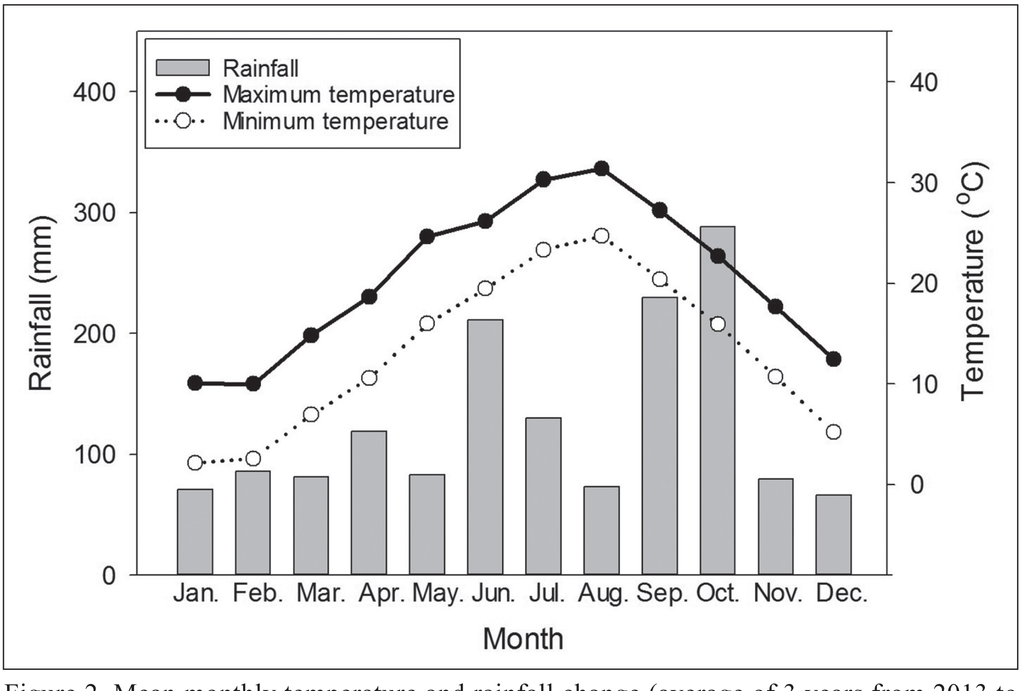


Figure 2. Mean monthly temperature and rainfall change (average of 3 years from 2013 to 2015) in Chiba, Japan (Japan Meteorological Agency 2016).

Initially, we planted 11 species (20 plants for each plant species) in 9-cm pots. Characteristics of planted flora on the Harappa roof are shown in Table 2. We identified all plant species and employed the ACFOR scale (A = abundant, C = common,

Figure 3. Harappa green roof, Chiba University, 10 July 2015.

Table 2. Characteristics of planted floral species on Harappa roof at Chiba University.

| Family | Species | Distribution |
| --- | --- | --- |
| Asparagaceae | *Barnardia japonica* (Thunb.) Schult. et Schult.f. (Japanese Jacinth) | Japan, China, Korea |
| Asteraceae | *Aster microcephalus* (Miq.) Franch. et Sav. var. *ovatus* (Franch. et Sav.) Soejima et Mot.Ito | Japan |
| | *Aster yomena* (Kitam.) Honda var. *dentatus* (Kitam.) H. Hara | Japan |
| Campanulaceae | *Platycodon grandiflorus* (Jacq.) (Balloon Flower) | Japan, China, Korea, East Siberia |
| Caryophyllaceae | *Dianthus superbus* L. var. *longicalycinus* (Maxim.) Williams | Japan, China, Korea, Taiwan |
| Lythraceae | *Lythrum anceps* (Koehne) Makino (Spiked Loosestrife) | Japan, Korea |
| Orchidaceae | *Spiranthes sinensis* (Pers.) Ames (Austral Ladies' Tresses) | Japan, Chiba, Siberia |
| Rosaceae | *Potentilla hebiichigo* Yonek. et H. Ohashi | Japan, China, Korea, East Asia |
| Rutaceae | *Zanthoxylum piperitum* (L.) DC. (Japanese Pepper) | Japan, Korea |
| Verbenaceae | *Phyla nodiflora* (L.) Greene (Capeweed) | Tropical and subtropical country |
| Violaceae | *Viola mandshurica* W. Becker (Sumire) | Japan, China, Siberia |

F = frequent, O = occasional, or R = rare within the given area; Louette, et al. 2007) to classify abundance. We convened workshops so that local residents could be involved in the design process, including collection of materials and construction. Neither irrigation nor maintenance was conducted. We set out 3 recycled wash bowls to provide temporary water-capture stations and added piles of stones, empty flower pots, dead branches, and 4 substrate-filled tires to create wildlife habitat.

The Biotope roof (150 $m^2$) was installed in spring 2002 on a 9-story building (Fig. 4). The roof was framed by a concrete-block retaining wall. The roof design consisted of a barrier membrane, a drainage layer (Qanat mat®), and a substrate (Laputa soil Ecola®) with a depth of 50 cm. The substrate was composed of crushed, autoclaved, aerated concrete mixed with 20% by volume of organic matter content; most of the species planted were native. All green-roof materials were obtained from Hibiya Amenis Corporation (Chiba, Japan). A pond (12 $m^2$, 50 cm deep) was installed and planted with *Typha latifolia* L. (Common Cattail). The Biotope roof received full sunlight in the morning but was shaded in the afternoon. Repairs, such as additional plantings and removal of stressed plants, were carried out in spring 2012, for a total of 12 species of trees, 18 species of shrubs, and 8 species of forbs planted (Table 3). An irrigation system was installed in 2012. Weeding of invasive species was carried out once monthly. Nagase and Nomura (2014) described the previous planting scheme of this roof and the evaluation of plant development and arthropod colonization.

## Methods

We sampled arthropods from 2013 to 2015 between 0900 h and 1300 h on 17 occasions (2013: 23 August, 10 September, 5 November, 16 December; 2014:

Figure 4. Biotope green roof, Chiba University,10 July 2015.

Table 3. Characteristics of cultivated plant species on biotope roof in Chiba University. [Table continued on next page.]

| Family | Species | Distribution |
|---|---|---|
| Adoxaceae | *Viburnum dilatatum* Thunb. (Linden Arrowwood) | Japan |
| Aquifoliaceae | *Ilex crenata* Thunb. (Japanese Holly) | China |
| | *Ilex integra* Thunb. (The Mochi Tree) | Japan, China, Taiwan |
| Araliaceae | *Fatsia japonica* (Thunb.) Decne. et Planch. (Glossy-leaf Paper Plant) | Japan, Korea |
| Asparagaceae | *Hosta* sp. | Japan, East Asia |
| | *Liriope muscari* (Decne.) L.H.Bailey (Big Blue Lilyturf) | Japan, East Asia |
| | *Ophiopogon japonicas* (Thunb.) Ker Gawl. (Dwarf Lilyturf) | Japan, East Asia |
| Asteraceae | *Eupatorium fortunei* Thunb. | Japan, China, Korea |
| | *Farfugium japonicum* (L.) Kitamura (Leopard Plant) | Japan, China, Korea, Taiwan |
| Aucubaceae | *Aucuba japonica* Thunb. (Japanese Aucuba) | Japan, China, Korea |
| Berberidaceae | *Nandina domestica* Thunb. (Heavenly Bamboo) | China |
| Calycanthaceae | *Chimonanthus praecox* (L.) Link (Wintersweet) | China |
| Caprifoliaceae | *Abelia × grandiflora* (André) Rehd. (Glossy Abelia) | Cultivar |
| Clusiaceae | *Hypericum chinense* L. | China |
| Cornaceae | *Cornus kousa* F. Buerger ex Hance (Korean Dogwood) | Japan, East Asia |
| Cyperaceae | *Carex kobomugi* Ohwi (Japanese Sedge) | Japan, China, Korea, Taiwan |
| Equisetaceae | *Equisetum hyemale* L. (Rough Horsetail) | Japan |
| Ericaceae | *Enkianthus perulatus* C.K. Schneid. (White Enkianthus) | Japan |
| | *Rhododendron indicum* (L.) Sweet (Azalia) | Cultivar |
| Fabaceae | *Lespedeza bicolor* Turcz. (Shrubby Bushclover) | Japan, China, Korea |
| | *Quercus serrata* Thunb. (Konara) | Japan, China, Korea |
| | *Quercus glauca* Thunb. (Ring-cupped Oak) | Japan, China, Taiwan |
| | *Quercus phylliraeoides* A. Gray (Ubamegashi) | Japan, China |
| Hamamelidaceae | *Loropetalum chinense* var. *rubra* (R. Brown) Oliver (Chinese Fringe Flower) | Japan, China, India |
| Hydrangeaceae | *Hydrangea macrophylla* (Thunb.) Ser. (Bigleaf Hydrangea) | Cultivar |
| | *Hydrangea macrophylla* f. *normalis* (Thunb.) Ser. | Japan |
| | *Hydrangea paniculata* Sieb. et Zucc. (Panicled Hydrangea) | Japan |
| Hypericaceae | *Hypericum monogynum* L. (St John's Wort) | China |
| Iridaceae | *Iris japonica* Thunb. (Fringed Iris) | China |
| Lauraceae | *Cinnamomum camphora* (L.) J. Presl (Camphor Tree) | China Taiwan, Vietnam |
| Liliaceae | *Tricyrtis hirta* (Thunb.) Hook (Japanese Toad Lily) | Japan, Korea, Taiwan |
| Magnoliaceae | *Michelia figo* (Lour.) DC. (Port Wine Magnolia) | China |
| Malvaceae | *Hibiscus syriacus* L. (Rose Mallow) | China |
| Myricaceae | *Myrica rubra* Siebold et Zucc. (Japanese Bayberry) | Japan, China |

16 April, 23 May, 20 June, 18 July, 29 August, 30 September, 3 November; 2015: 14 May, 17 June, 10 July, 7 August, 11 September, and 22 October). We divided the 2 roofs into 14 quadrats (3 m × 3 m) in which we swept an insect net 20 times. All specimens were released after we employed a hand-held 10x magnifier and several publications (Enjyu 2013, Morimoto and Hayashi 2007, Tomokuni et al. 1993) to identify all of those collected to species or morphospecies. On the

Table 3, continued.

| Family | Species | Distribution |
|---|---|---|
| Oleaceae | *Forsythia suspensa* (Thunb.) Vahl (Weeping Forsythia) | China |
| | *Ligustrum obtusifolium* Siebold et Zucc. (Border Privet) | Japan, Korea |
| | *Osmanthus fragrans* var. *aurantiacus* Lour. (Kinmokusei) | China |
| Orchidaceae | *Bletilla striata* (Thunb.) Rchb.f. (Hyacinth Orchid) | Japan, China, Taiwan |
| | *Calanthe discolor* Lindl. (Ebine) | Japan, China, Korea |
| Oxalidaceae | *Oxalis debilis* Kunth subsp. *corymbosa* (DC.) O. Bolos et Vigo (Large-flowered Pink-sorrel) | South America |
| Pentaphylacaceae | *Cleyera japonica* Thunb. (Sakaki) | Japan, China, Korea, Taiwan |
| Rosaceae | *Cotoneaster holizontalis* Decne. (Rockspray Cotoneaster) | China |
| | *Photinia × fraseri* W.J. Dress ‘Red Robin’ (Christmas Berry) | Cultivar |
| | *Photinia glabra* (Thunb.) Franch. & Sav. (Japanese Photinia) | Japan |
| | *Rhaphiolepis umbellata* (Thunb.) Makino (Indian Hawthorn) | Japan, Korea, Taiwan |
| | *Spiraea thunbergii* Siebold ex Blume (Thunberg’s Meadowsweet) | Japan |
| Rubiaceae | *Gardenia jasminoides* Ellis (Cape Jasmine) | Japan, East Asia |
| | *Serisa japonica* (Thunb.) Thunb. (Snowbush) | Japan, East Asia |
| Rutaceae | *Citrus unshiu* (Swingle) Marcow. (Unshu Mikan) | Japan, China |
| | *Citrus junos* (Makino) Siebold ex Tanaka (Yuzu) | China |
| | *Poncirus trifoliata* L. (Japanese Bitter-orange) | China, Korea |
| | *Zanthoxylum piperitum* (L.) DC. (Japanese Pepper Tree) | Japan, Korea |
| Scrophulariaceae | *Buddleja davidii* Franch. (Butterfly-bush) | Japan, China |
| Theaceae | *Camellia japonica* L. (Japanese Camellia) | Japan, China, Korea, Taiwan |
| | *Camellia sasanqua* Thunb. (Sasanqua Camellia) | Japan, China |
| | *Eurya japonica* Thunb. (East Asian Eurya) | Japan, China, Korea |
| Thymelaeaceae | *Daphne odora* Thunb. (Winter Daphne) | China |
| Typhaceae | *Typha latifolia* L. (Broadleaf Cattail) | Japan, North and South America, Europe, Eurasia, Africa |
| Valerianaceae | *Patrinia scabiosifolia* Fisch. ex Trevir. (Patrinia) | Japan, China, East Siberia |
| Verbenaceae | *Callicarpa dichotoma* (Lour.) K. Koch (Purple Beautyberry) | Japan, China, Korea, Vietnam |
| Xanthorrhoeaceae | *Hemerocallis* hybrid (Hort.) (daylily) | Japan, East Asia |

Harappa roof, we carried out surveys of spontaneously colonizing plant species and arthropods on the same day. We collected for later identification all specimens that were impossible to identify on-site. Although our study focused on arthropods, we also observed and identified vertebrates.

In order to compare arthropod diversity between the Biotope and Harappa roofs, we used species richness and abundance data to calculate Simpson's diversity index (D) and the Shannon–Wiener index (H'). The analysis was carried out using Excel 2016. We employed a *t*-test ($P < 0.05$; Minitab v16) to examine whether species richness was significantly different between the Biotope and Harappa roofs over time.

## Results

Overall, the arthropods collected on both roof types were species commonly observed in urban areas, and we observed no endangered species in this study. Richness (orders, species, individuals), diversity indices (Shannon–Wiener, Simpson), and temporal patterns are shown in Table 4.

Over the study period, we observed 71 species (16 orders) and 93 species (13 orders) on the Harappa and Biotope roofs, respectively (Table 4, Appendices 1, 2). On the Harappa roof, 40 species were grassland specialists, as opposed to 30 species on the Biotope roof. Seven species of exotic fauna were observed on the Harappa roof vs. 8 species on the Biotope roof. Some, including the Orthopterans *Patanga japonica* Bolívar, *Ornebius kanetataki* Matsumura, *Phaneroptera falcata* Redtenbacher, and *Euconocephalus thunbergi* Montrouzier (all Hexapoda) were observed to spend their entire life-cycle on the Biotope roof.

Diversity indices were high on both roof types (Table 4), and species richness varied among arthropod groups (Table 5). The most abundant taxa were Hemiptera (e.g., *Plautia stali* Scott [a stink bug], aphids, and leafhoppers), Coleoptera (e.g., *Harmonia axyridis* Pallas [a lady beetle] and *Gonocephalum japanum* Motschulsky [a darkling beetle]) and Lepidoptera (e.g., *Papilio xuthus* L. [Common Swallowtail] and *Mamestra brassicae* L. [a noctuid moth]) on both roofs.

Table 4. The number of faunal taxa (orders, species, and individuals), biodiversity indices (Shannon–Wiener, Simpson), mean number of faunal species on each sampling date in Harappa roof and Biotope roof in Chiba University. Means (± SE) with the different letter differ significantly from each other ($t = 7.2$, df = 23, $P < 0.01$). Differences in mean number of fauna species Harappa roof and Biotope roof were recorded on each sampling date over the survey period.

| Statistic | Harappa roof (extensive) | Biotope roof (intensive) |
|---|---|---|
| Total number of orders | 16 | 13 |
| Total number of species | 71 | 93 |
| Total number of individuals | 330 | 1003 |
| Total number of grassland species | 40 | 30 |
| Total number of exotic species | 7 | 8 |
| Shannon–Wiener diversity index | 3.62 | 3.79 |
| Simpson diversity index | 0.95 | 0.97 |
| Mean number of faunal species on each sampling date | 8.32 ± 0.79$^{b*}$ | 23.26 ± 1.94$^{a}$ |

Temporal changes also varied between roofs (Fig. 5). The Biotope roof showed significantly greater mean faunal abundance ($t = 7.2$, df = 23, $P < 0.01$). The maximum richness for a single sampling event was 14 species (both June 2014 and June

Table 5. The number of faunal species (*n*) and percentage of total (%) of each order on a Harappa roof and a Biotope roof in Chiba University.

| | Harappa roof | | Biotope roof | |
|---|---|---|---|---|
| Order | *n* | % | *n* | % |
| Odonata | 3 | 4.2 | 3 | 3.2 |
| Orthoptera | 4 | 5.6 | 11 | 11.8 |
| Blattodea | 1 | 1.4 | 0 | 0.0 |
| Mantodea | 1 | 1.4 | 1 | 1.1 |
| Psocodea | 0 | 0.0 | 1 | 1.1 |
| Thysanoptera | 1 | 1.4 | 0 | 0.0 |
| Hemiptera | 16 | 22.5 | 18 | 19.4 |
| Neuroptera | 0 | 0.0 | 1 | 1.1 |
| Coleoptera | 11 | 15.5 | 16 | 17.2 |
| Diptera | 7 | 9.9 | 7 | 7.5 |
| Lepidoptera | 16 | 22.5 | 16 | 17.2 |
| Hymenoptera | 5 | 7.0 | 10 | 10.8 |
| Araneae | 4 | 5.6 | 7 | 7.5 |
| Acari | 1 | 1.4 | 1 | 1.1 |
| Isopoda | 1 | 1.4 | 1 | 1.1 |
| Total | 71 | 100.0 | 93 | 100.0 |

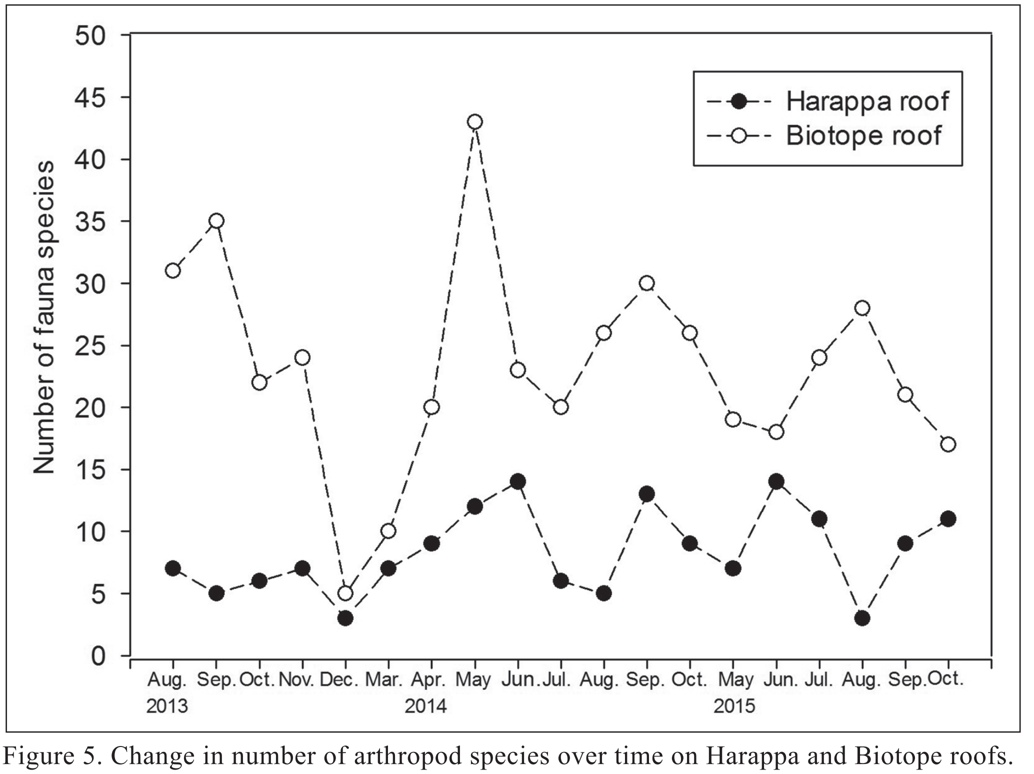

Figure 5. Change in number of arthropod species over time on Harappa and Biotope roofs.

2015) for the Harappa roof and 43 species (May 2014) for the Biotope roof. The minimum number was 3 (both December 2013 and August 2015) for the Harappa and 14 (December 2013) for the Biotope roof.

Native and exotic species were equally represented, as were annual and perennial life forms (Table 6; Appendix 3). The most abundant species were *Vicia sativa* L. (Common Vetch), *Plantago lanceolata* L. (English Platain), and *Setaria viridis* (L.) P. Beauv. (Foxtail Millet). The arrival rate of colonizing plant species varied over time on the Harappa roof (Fig. 6). We documented the fewest arrivals in August of each year, when temperatures were high and rainfall was low. The number of plant species was highest (>15 species) in spring and autumn.

## Discussion

The arthropods collected from both roofs in this study were common to urban areas. The results of previous studies have been varied in this regard. Hwang and

Table 6. Native or exotic species and plant life-cycle of spontaneously colonizing plant species on a Harappa roof in Chiba University.

| Native or exotic | *n* | % | Plant life cycle | *n* | % |
|---|---|---|---|---|---|
| Native species | 26 | 55.3 | Annual or biennial species | 26 | 55.3 |
| Exotic species | 21 | 44.7 | Perennial species | 21 | 44.7 |
| Total | 47 | 100.0 | Total | 47 | 100.0 |

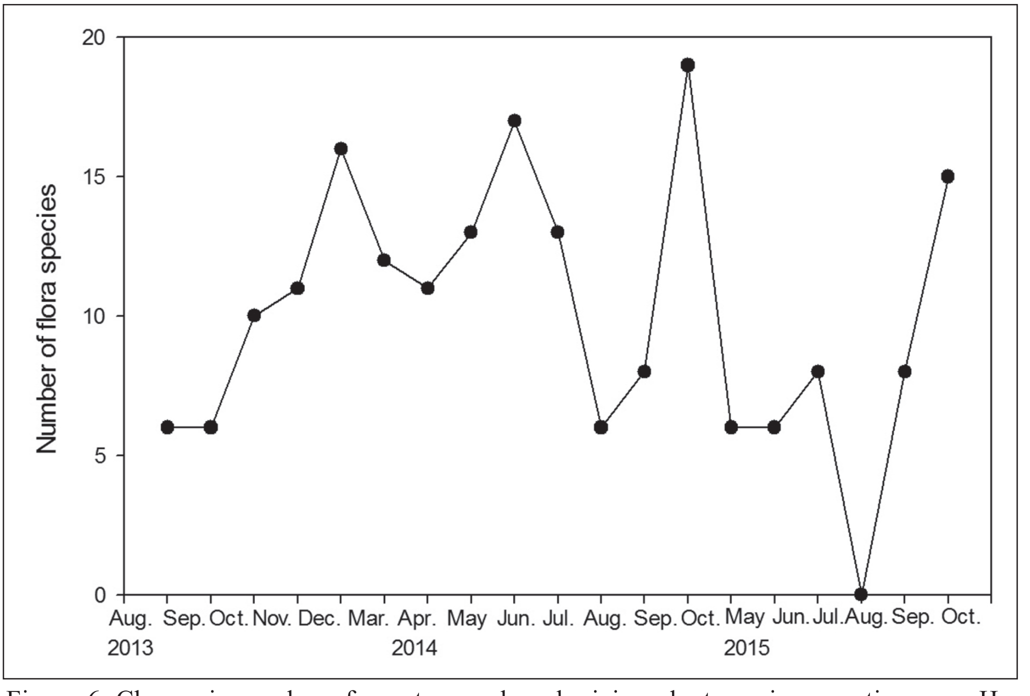


Figure 6. Change in number of spontaneously colonizing plant species over time on a Harappa roof in Chiba University.

Yue (2015) studied green-roof fauna in Singapore and found mostly bees, hornets, and wasps and no endangered species. Other surveys have found that green roofs support uncommon arthropod species (Brenneisen 2006, Kadas 2006, Majka and MacIvor 2009). This result may be partly related to different sampling protocols employed; those studies used pitfall traps, while we used sweep nets.

We found that the Biotope roof had greater species richness and higher abundance than the Harappa roof. This result was supported by previous studies, which also compared diversity on extensive and intensive roofs (Coffman 2007, Madre et al. 2013). The Biotope roof might provide a more consistent environment for fauna and flora because of their stable planted vegetation (including trees), thick substrate (50 cm), and irrigation systems. However, with a comparison of only a single example of each roof type, we cannot generalize based on the other differences between the 2 roof sites. The building height and age of the green roofs also differed, making direct faunal comparisons difficult.

In contrast, the Harappa roof type has unstable vegetation because of a thin substrate and the lack of summer irrigation. The Harappa roof became completely brown during the summer, and we found few arthropods during that period. One month later, both vegetation and arthropods recolonized. This finding suggests that the Harappa roof was used as a temporary habitat. Braaker et al. (2014) studied habitat connectivity of arthropod communities and demonstrated their movement between green roofs and ground sites. Such an exchange between communities is especially crucial on green roofs because well-connected communities are predicted to be more resilient to stochastic disturbance events, and thus, have a higher chance of persistence (Fahring and Merriam 1994).

Previous work has shown that roof age affects arthropod community composition (Iwasaki et al. 2005) and that roof height affects nesting activity of bees and wasps (MacIvor 2016). Further study is necessary to examine the importance of connectivity and proximity among green roofs, as well as the influence of ground-level biodiversity (Hwang and Yue 2015, MacIvor and Lundholm 2011).

Although the Harappa roof had less richness than the Biotope roof, it provided habitats, particularly for grassland specialists. In Japan, there was 1.2 million ha of grassland habitat in the 1960s, but this area declined to 0.4 million ha in the 2010s (Ogura 2006). Grasslands are primarily lost through urban development; however, trees are often saved and/or added due to their frequent role in urban greening (MLITT 2009). Thus, grassland conservation is critical (Ishii and Nakamura 2012), and Harappa roofs could play a role in the conservation of grassland specialists.

The Harappa roof supported 47 spontaneously colonizing plant species, but none of these was endangered or rare. The dominant plant species were *Vicia sativa* L. (Common vetch; native), *Plantago lanceolata* L.(Foxtail Millet) (English Plantain; non-native) and *Setaria viridis* (L.) P. Beauv (Wild Foxtail Millet; native); richness was highest in the Poaceae (grass family). In previous long-term research of green roofs in Germany (Catalano et al. 2016, Köhler and Poll 2010), Poaceae was the most commonly observed family as well. In a previous study of spontaneous plant colonizers on a Biotope roof, *Solidago altissima* L. (Tall Goldenrod) and *Miscanthus sinensis* Andersson (Zebra Grass) (both invasive) were the most abundant species (Nagase and Nomura 2014). However, we observed few of these specimens on the Harappa roof during this study. Their colonization was likely prevented by the Harappa roof's thin substrate because these are large-bodied plants (Dunnett and Kingsbury 2008). There was concern that dense brush might develop on Harappa roofs, which would require frequent cutting; however, the vegetation was short, and no maintenance was needed over the study period. These results suggest that it is possible to control the amount of vegetation using different depths of substrate.

The new concept of the Harappa roof was established successfully, and it provides a unique opportunity for participatory design and maintenance. Harappa roof development can lead to important opportunities for environmental education, cost reduction, and positive public opinion. These roofs can be made completely from recycled materials. Green roofs are expected to improve urban environments. Plastic materials are frequently used for root barriers, drainage mats, and other purposes; thus, using recycled materials can reduce the life-cycle cost of a green roof. Harappa roofs are also much cheaper than Biotope roofs (at least 25% less in initial cost), and it was easy for citizens to get involved in the design process and in construction. In Japan and around the world, there are still too few examples of public participation in green-roof creation. Successful implementation of green roofs for urban biodiversity depends on participation of urban citizens, and a "citizen scientist" model is needed to facilitate public participation in green roof design (Francis and Lorimer 2011).

## Conclusion

It is clear that biotope roofs encourage urban biodiversity. However, the results of this study suggest that Harappa roofs might be able to provide habitats, particularly for grassland fauna, without maintenance or irrigation. Future research should test several hypotheses using multiple examples of each type of biodiversity roof. First, greater structural diversity and standing biomass should make Biotope roofs a more stable habitat, resulting in more consistent faunal diversity and abundance over time. Harappa roofs would represent temporary habitats due to large changes in vegetation cover and biomass during the growing season. Second, we predict that Harappa roofs will preferentially support arthropod species from grassland habitats due to the similarity of their vegetation to ground-level grasslands. Third, aggressively invasive plant species are likely to be less common on Harappa roofs, because low-fertility soils and frequent drought should limit their ability to colonize and spread on Harappa roofs.

To further develop green roofs for biodiversity, it is necessary to study them from both the natural (e.g., long-term research, regional variation) and social science perspective (e.g., citizen involvement, psychological effects). Detailed guidelines must be made available in order to set standards for green–roof design and biodiversity optimization.

**Acknowledgments**

This work was supported by JSPS KAKENHI Grant Number JP 26750001 and Campus Asia Program Inter University Exchange Program (2010–2014, 2016–2021) ( Ministry of Education, Culture, Sports, Science and Technology). We thank Dr. Scott MacIvor (University of Toronto), Dr. Olyssa Starry (Portland State University), Dr. Jeremy Lundholm (St. Mary's University), and 2 anonymous reviewers for providing helpful comments on our manuscript.

**Literature Cited**

Baumann, N. 2006. Ground-nesting birds on green roofs in Switzerland: Preliminary observations. Urban Habitats 4:37–44.

Baumann, N., and F. Kasten. 2010. Green roofs: Urban habitats for ground-nesting birds and plants. Pp. 348–362, *In* N. Muller, P. Werner, and J.G. Kelcy (Eds). Urban Biodiversity and Design. John Wiley and Sons, Chichester, UK. 648 pp.

Braaker, S., J., Ghazoul, M.K. Obrist, and M. Moretti. 2014. Habitat connectivity shapes urban arthropod communities: The key role of green roofs. Ecology 95:1010–1021.

Brenneisen, S. 2006. Space for urban wildlife: Designing Green roofs as Habitats in Switzerland, Urban Habitats 4:27–36.

Catalano, C., C., Marcenò, V.A. Laudicina, and R. Guarino. 2016. Thirty years of unmanaged green roofs: Ecological research and design implications. Landscape and Urban Planning 149:11–19.

Coffman, R.R. 2007. Vegetated roof systems: Design, productivity, retention, habitat, and sustainability in green roof and ecoroof technology. Ph.D. Dissertation. Graduate School of The Ohio State University, Columbus, OH, USA.

Coffman, R.R., and G. Davis. 2005. Insect and avian fauna presence on the Ford assembly plant ecoroof. Pp. 457–468, *In* Proceedings of the Third Annual Greening Rooftops for Sustainable Communities Conference (4–6 May 2005, Washington, DC). The Cardinal Group, Toronto, Canada.

Coffman, R.R., and T. Waite. 2011. Vegetated roofs as reconciled habitats: Rapid assays beyond mere species counts. Urban Habitats. Available online at http://www.urbanhabitats.org/v06n01/vegetatedroofs_full.html. Accessed 1 August 2016.

Dunnett, N., and N. Kingsbury. 2008. Planting Green Roofs and Living Walls, 2$^{nd}$ Edition. Timber Press, Portland, OR, USA. 336 pp.

Enjyu, M. 2013. Insects of Japan 1400, Volumes 1 and 2. Bun-Ichi, Shinjyuku, Tokyo. 320 pp.

Fahring, L., and G. Meriram. 1994. Conservation of fragmented populations. Conservation Biology 8:50−59.

Francis, R.A., and J. Lorimer. 2011. Urban reconciliation ecology: The potential of living roofs and walls. Journal of Environmental Management 92:1429–1437.

Gedge, D. 2003. From rubble to redstarts. Pp. 233–241, *In* Proceedings of First North American Green Roof Conference: Greening Rooftops for Sustainable Communities (29–30 May 2003, Chicago). The Cardinal Group, Toronto, Canada.

Grant, G. 2006. Extensive green roofs in London. Urban Habitats 4:51–65.

Gray, J. 2015. Sustainable build: Brownfield sites. Available online at http://www.sustainablebuild.co.uk/brownfieldsites.html. Accessed 1 August 2016.

Grimm, N.B., S.H. Faeth, N.E. Golubiewski, C.L. Redman, J.G. Wu, X.M. Bai, and J.M. Briggs 2008. Global change and the ecology of cities. Science 319:756–760.

Güneralp, B., and K. C. Seto. 2008. Environmental impacts of urban growth from an integrated dynamic perspective: A case study of Shenzhen, South China. Global Environmental Change 18:720–735.

Hwang, Y., and Z. Yue. 2015. Observation of biodiversity on minimally managed green roofs in a tropical city. Journal of Living Architecture 2:9–26.

Ishii, M., and M. Nakamura. 2012. Development and future of insect conservation in Japan. Pp. 339–357, *In* T. R. New (Ed). Insect Conservation: Past, Present and Prospects. Springer, Heidelberg, Germany. 436 pp.

Ishimatsu, J., and K. Ito. 2013. Brown/biodiverse roofs: A conservation action for threatened brownfields to support urban biodiversity. Landscape and Ecological Engineering 9:299–304.

Iwasaki, T., J.,Kato, T. Moriguchi, M. Handa, and K. Imai. 2005. Changes of the insect fauna at the high-rise roof garden constructed in Kasumigaseki, Tokyo. Japanese Institute of Landscape Architecture 3:22–25.

Japan Meteorological Agency. 2016. Weather, climate, and earthquake information, Available online at http://www.data.jma.go.jp/obd/stats/etrn/. Accessed 25 June 2016.

Kadas, G. 2006. Rare invertebrates colonizing green roofs in London. Urban Habitats 4:66–86.

Köhler, M., and P.H. Poll. 2010. Long-term performance of selected old Berlin green roofs in comparison to younger extensive green roofs in Berlin. Ecological Engineering 36:722–729.

Louette, G., T. De Bie, J. Vandekerkhove, S. Declerck, and L. De Meester. 2007. Analysis of the inland cladocerans of Flanders (Belgium): Interring changes over the past 70 years. Belgian Journal of Zoology 137:117–123.

Lundholm, J.T. 2006. Green roofs and facades: A habitat-template approach. Urban Habitats 4:87–101.

MacIvor, J.S. 2016. Building height matters: Nesting activity of bees and wasps on vegetated roofs. Israel Journal of Ecology and Evolution. DOI: 10.1080/15659801.2015.1052635. MacIvor, J.S., and J. Lundholm. 2011. Insect species composition and diversity on intensive green roofs and adjacent level-ground habitats. Urban Ecosystems 14:225–241.

MacIvor, J.S., and Ksiazek, K. 2015. Invertebrates on green roofs. Pp. 333–355, *In* R.K. Sutton (Ed.). Green Roof Ecosystems. Springer, Switzerland. 447 pp.

Madre, F., A. Vergnes, N. Machon, and P. Clergeau. 2013. A comparison of three types of green roof as habitats for arthropods. Ecological Engineering 57:109–117

Majka, C.G. and J.S. MacIvor, 2009. *Otiorhynchus porcatus* (Coleoptera: Curculionidae): A European root weevil newly discovered in the Canadian Maritime Provinces. Journal of the Acadian Entomological Society 5:27–31.

Ministry of Land, Infrastructure, Transport, and Tourism (MLITT). 2009. Green roofs. Available online at http://www.mlit.go.jp/crd/park/shisaku/gi_kaihatsu/okujyo/panf.html. Accessed 25 June 2016.

MLITT. 2014. Annual survey of installment of green roofs and living walls. Available online at http://www.mlit.go.jp/. Accessed 25 June 2016.

Morimoto, K., and M. Hayashi. 2007. The Coleoptera of Japan in Color, 4$^{th}$ Edition. Hoikusya, Osaka. 323 pp.

Nagase, A., and M. Nomura. 2014. An evaluation of one example of biotope roof in Japan: Plant development and invertebrate colonisation after 8 years. Urban Forestry and Urban Greening 13:714–724.

Nagase, A., S. Komori, E. Kumasaka, and S. Koyama. 2015. Experience with plants influencing perception of extensive green roofs. Proceedings of 17$^{th}$ Japan Society of Kansei Engineering, Tokyo, Japan.

Ogura, J. 2006. The transition of grassland area in Japan. Journal of Kyoto Seika University 30:159–172.

Organization for Landscape and Urban Infrastructure. 2016. Available online at https://urbangreen.or.jp/. Accessed 1 August 2016.

Shuowen, T., 2006. A study on park maintenance as a children's outdoor environment. Hokkaido University Collection of Scholarly and Academic Papers 28:1–84.

Tomokuni, M., Y. Yasunaga, M.Takai, I. Yamashita, M.Kawamura, and T. Kawasawa. 1993. A Field Guide to Japanese Bugs. Zenkokunosonkyouikukyoukai, Tokyo, Japan. 380 pp.

Williams, N.G., J. Lundholm, and J.S. MacIvor. 2014. Do green roofs help urban biodiversity conservation? Journal of Applied Ecology 51:1643–1649.

Yamada, Y., Y. Sone, T. Aoki, M. Nomura, and A. Nagase. 2013. Introduction of biodiverse roofs in Japanese urban areas: Possibilities and challenges. Journal of the Japanese Institute of Landscape Architecture 76:71–674.

**Appendix 1**. List of fauna species on Harappa roof in Chiba University.

| Class/ Order | Species | Grassland species | Native or Exotic |
|---|---|---|---|
| Aves | | | |
| Passeriformes | *Corvus macrorhynchos* Wagler | | Native |
| | *Hypsipetes amaurotis* Temminck | | Native |
| | *Motacilla alba lugens* Gloger | | Exotic |
| | *Passer montanus* L. | | Native |
| Columbiformes | *Columba livia* Gmelin | | Exotic |
| Reptilia | | | |
| Squamata | *Plestiodon japonicas* Peters | ○ | Native |
| Insecta | | | |
| Odonata | *Ischnura senegalensis* Rambur | | Native |
| | *Pantala flavescens* Fabricius | | Native |
| | *Sympetrum frequens* Sélys | | Exotic |
| Orthoptera | *Dianemobius nigrofasciatus* Matsumura | ○ | Native |
| | *Oedaleus infernalis* Sauss | ○ | Native |
| | *Patanga japonica* Bolívar | ○ | Native |
| | *Teleogryllus emma* Ohmachi & Matsuura | ○ | Native |
| Blattodea | *Periplaneta fuliginosa* Serville | | Native |
| Mantodea | *Hierodula patellifera* Serville | | Native |
| Thysanoptera | Thysanoptera sp. | | - |
| Hemiptera | Aphidoidea sp. | | - |
| | Cicadellidae sp. | | - |
| | Delphacidae sp. | ○ | - |
| | *Dolycoris baccarum* L. | ○ | Native |
| | *Geocoris proteus* Distant | ○ | Native |
| | *Getomus pygmaeus* Dallas | ○ | Native |
| | Lygaeoidea sp. | ○ | Native |
| | *Nabis kinbergii* Reuter | ○ | Native |
| | *Orius* sp. | ○ | - |
| | *Pachygrontha antennata* Uhler | ○ | Native |
| | *Phyrrhocoris sinuaticollis* Reuter | ○ | Native |
| | *Plautia stali* Scott | ○ | Native |
| | *Riptortus pedestris* Trusted | ○ | Native |
| | *Trigonotylus caelestialium* Kirkaldy | ○ | Native |
| | Typhlocybinae sp. | | Native |
| | *Yemma exilis* Horváth | ○ | Native |
| Coleoptera | Cheilomenes sexmaculata Fabricius | | Native |
| | *Coccinella septempunctata* L. | | Native |
| | Curculionoidae sp. | | - |
| | *Gonocephalum japanum* Motschulsky | ○ | Native |
| | Halticinae sp. | ○ | Native |

| Class/ Order | Species | Grassland species | Native or Exotic |
|---|---|---|---|
| | *Harmonia axyridis* Pallas | | Native |
| | Histeridae sp. | | Native |
| | *Hypera postica* Gyllenhal | ○ | Exotic |
| | *Illeis koebelei* Timberlake | | Native |
| | *Paederus fuscipes* Curtis | ○ | Native |
| | Staphylinidae sp. | | Native |
| Diptera | Chironomidae sp. | | Native |
| | Drosophilidae sp. | | Native |
| | *Sphaerophoria philanthus* Meigen | ○ | Native |
| | *Episyrphus balteatus* De Geer | ○ | Native |
| | Syrphinae sp. | | Native |
| | Tephritidae sp. | | - |
| | Tipulidae sp. | | Native |
| Lepidoptera | *Argyreus hyperbius* L. | ○ | Exotic |
| | *Agrotis segetum* Denis & Schiffermüller | | Native |
| | Crambidae sp. | ○ | Native |
| | *Helicoverpa armigera armigera* Hübner | ○ | Native |
| | *Mamestra brassicae* L. | ○ | Native |
| | Noctuidae sp. | | - |
| | *Palpita nigropunctalis* Bremer | | Native |
| | *Papilio xuthus* L. | | Native |
| | *Parnara guttata* Bremer & Grey | ○ | Native |
| | *Potanthus flavum* Murray | ○ | Native |
| | *Pediasia teterrellus* Zincken | ○ | Native |
| | *Pieris rapae* L. | ○ | Exotic |
| | Pyralidae sp. | | Native |
| | *Lycaena phlaeas* L. | ○ | Native |
| | Oncocera sp. | ○ | Native |
| | *Zizeeria maha* Kollar | ○ | Native |
| Hymenoptera | *Camponotus japonicus* Mayr | ○ | Native |
| | *Apis mellifera* L. | | Exotic |
| | *Campsomeriella annulata* Fabricius | | Native |
| | *Formica japonica* Motschoulsky | ○ | Native |
| | *Tetramorium tsushimae* Emery | ○ | Native |
| Arachnida | | | |
| Araneae | Lycosidae sp. | | Native |
| | *Misumenops tricuspidatus* Fabricius | ○ | Native |
| | Salticidae sp. | | Native |
| | Thomisidae sp. | ○ | Native |
| Acari | *Balaustium murorum* Hermann | | Native |
| Malacostraca | | | |
| Isopoda | *Armadillidium vulgare* Latreille | | Exotic |

**Appendix 2**. List of fauna species on a Biotope roof in Chiba University.

| Class/ Order | Species | Grassland species | Native or Exotic |
|---|---|---|---|
| Aves | | | |
| Passeriformes | *Corvus macrorhynchos* Wagler | - | Native |
| | *Motacilla alba lugens* Gloger | - | Native |
| Columbiformes | *Columba livia* Gmelin | - | Exotic |
| Insecta | | | |
| Odonata | *Lestes sponsa* Hansemann | - | Native |
| | *Orthetrum albistylum speciosum* Uhler | - | Native |
| | *Pantala flavescens* Fabricius | - | Native |
| Orthoptera | *Acrida cinerea* Thunberg | ○ | Native |
| | *Atractomorpha lata* Mochulsky | ○ | Native |
| | *Euconocephalus thunbergi* Montrouzier | ○ | Native |
| | *Oecanthus euryelytra* Ichikawa | ○ | Native |
| | *Ornebius kanetataki* Matsumura | - | Native |
| | *Patanga japonica* Bolívar | ○ | Native |
| | *Phaneroptera falcata* Redtenbacher | ○ | Native |
| | *Polionemobius micado* Shiraki | ○ | Native |
| | *Teleogryllus emma* Ohmachi & Matsuura | ○ | Native |
| | *Tettigonia orientalis* Uvarov | - | Native |
| | *Velarifictorus micado* Saussure | - | Native |
| Mantodea | *Tenodera aridifolia* Stoll | ○ | Native |
| Neuroptera | Chrysopidae sp. | - | Native |
| Hemiptera | *Anisops ogasawarensis* Walker | - | Native |
| | *Ceroplastes ceriferus* Fabricius | - | Native |
| | *Ceroplastes rubens* Maskell | - | Exotic |
| | Coccoidea sp. | - | - |
| | *Corythucha marmorata* Uhler | ○ | Exotic |
| | *Dulinius conchatus* Distant | ○ | Exotic |
| | *Geisha distinctissima* Walker | - | Native |
| | *Gerris lacustris latiabdominis* Miyamoto | - | Native |
| | *Graptopsaltria nigrofuscata* Motschulsky | - | Native |
| | *Kallitaxilla sinica* Walker | - | Native |
| | *Meimuna opalifera* Walker | - | Native |
| | *Microvelia douglasi* Scott | - | Native |
| | *Nipponaphis distyliicola* Monzen | - | Native |
| | *Nippolachnus piri* Matsumura | - | Native |
| | *Ossoides lineatus* Bierman | ○ | Native |
| | *Plautia stali* Scott | - | Native |
| | *Riptortus pedestris* Trusted | ○ | Native |
| | *Uroleucon nigrotuberculatum* Olive | ○ | Exotic |
| Coleoptera | *Agrypnus binodulus* Motschulsky | - | Native |
| | *Anomala albopilosa* Hope | - | Native |

| Class/ Order | Species | Grassland species | Native or Exotic |
|---|---|---|---|
| | *Anomala cuprea* Hope | - | Native |
| | *Anomala orientalis* Waterhouse | - | Native |
| | *Argopistes coccinelliformis* Motschulsky | - | Native |
| | *Aulacophora femoralis* Motschulsky | ○ | Native |
| | *Chilocorus kuwanae* Silvestri | ○ | Native |
| | *Coccinella septempunctata* L. | - | Native |
| | *Gametis jucunda* Faldermann | ○ | Native |
| | *Gonocephalum japanum* Motschulsky | - | Native |
| | *Harmonia axyridis* Pallas | - | Native |
| | *Illeis koebelei* Timberlake | - | Native |
| | *Linaeidea aenea* L. | - | Native |
| | *Pseudocneorhinus bifasciatus* Roelofs | - | Native |
| | *Propylaea japonica* Thunberg | - | Native |
| | *Pyrrhalta humeralis* Chen | - | Native |
| Diptera | Chironomidae sp. | - | Native |
| | *Episyrphus balteatus* De Geer | ○ | Native |
| | Milesiinae sp. | ○ | Native |
| | *Sphaerophoria indiana* Bigot | ○ | Native |
| | *Sphaerophoria menthastri* L. | ○ | Native |
| | Syrphinae sp. | - | Native |
| | Tipulidae sp. | - | Native |
| Lepidoptera | *Adoxophyes honmai* Yasuda | - | Native |
| | Crambidae sp | - | Native |
| | *Eumeta minuscula* Butler | - | Native |
| | Geometridae sp. | - | Native |
| | *Glyphodes perspectalis* Walker | - | Native |
| | *Homona magnanima* Diakonoff | - | Native |
| | *Mamestra brassicae* L. | ○ | Native |
| | *Palpita nigropunctalis* Bremer | - | Native |
| | *Papilio machaon* L. | ○ | Native |
| | *Papilio xuthus* L. | - | Native |
| | *Parapediasia teterella* Zincken | - | Exotic |
| | *Parnara guttata* Bremer & Grey | ○ | Native |
| | Pyralidae sp. | - | Native |
| | *Pelopidas mathias* Fabricius | ○ | Native |
| | Tortricidae sp. | - | Native |
| | *Vanessa indica* Herbst | ○ | Native |
| Hymenoptera | Braconidae sp. | - | Native |
| | *Camponotus japonicus* Mayr | ○ | Native |
| | Chalcididae sp. | - | - |
| | *Formica japonica* Motschoulsky | ○ | Native |
| | Icheumonidae sp. | - | Native |
| | *Megacampsomeris schulthessi* Betrem | - | Native |
| | Megachile sp. | - | Native |
| | *Pristomyrmex punctatus* Smith | ○ | Native |

| Class/ Order | Species | Grassland species | Native or Exotic |
|---|---|---|---|
| | *Tetramorium tsushimae* Emery | ○ | Native |
| | *Xylocopa appendiculata circumvolans* Latreille | - | Native |
| Psocodea | Psocodea sp. | - | Native |
| Arachnida | | | |
| Araneae | *Carrhotus xanthogramma* Latreille | - | Native |
| | *Hasarius adansoni* Audouin | - | Native |
| | *Misumenops* sp. | - | Native |
| | *Myrmarachne* sp. | - | Exotic |
| | *Nephila clavata* L. Koch | - | Native |
| | Thomisidae sp. | - | Native |
| Malacostraca | | | |
| Isopoda | *Armadillidium vulgare* Latreille | - | Native |
| | *Pholcus* sp. | - | Native |

**Appendix 3.** List of spontaneously colonizing plant species on a Harappa roof in Chiba University. ACFOR: A = abundant (≥30%), C = common (20–29%), F = frequent (10–19%), O = occasional (5–9%), R = rare (1–4%).

| Family | Species | Native or Exotic | Plant life-cycle | ACFOR scale |
|---|---|---|---|---|
| Amaryllidaceae | *Allium macrostemon* Bunge | Native | Perennial | R |
| Apiaceae | *Torilis japonica* (Houtt.) DC. | Native | Perennial | R |
| Asteraceae | *Bidens frondosa* L. | Exotic | Annual | R |
| | *Conyza canadensis* (L.) Cronquist | Exotic | Biennial | F |
| | *Conyza sumatrensis* (Retz.) E. Walker | Exotic | Perennial | F |
| | *Gnaphalium japonicum* Thunb | Native | Perennial | R |
| | *Solidago altissima* L. | Exotic | Perennial | R |
| | *Stenactis annuus* (L.) Cass. | Exotic | Annual | C |
| | *Youngia japonica* (L.) DC. | Native | Perennial | R |
| Boraginaceae | *Trigonotis peduncularis* (Trevir.) Benth. ex. Hemsl | Native | Annual | F |
| Brassicaceae | *Cardamine scutata* Thunb. | Exotic | Annual | O |
| Caryophyllaceae | *Cerastium glomeratum* Thuill. | Exotic | Annual | F |
| Chenopodiaceae | *Chenopodium album* L. | Exotic | Annual | R |
| Convolvulaceae | *Calystegia japonica* (Thunb.) Choisy | Native | Perennial | R |
| Cyperaceae | *Carex leucochlora* Bunge | Native | Perennial | O |
| | *Cyperus microiria* Steud. | Native | Annual | O |
| | *Cyperus rotundus* L. | Native | Perennial | O |
| Euphorbiaceae | *Acalypha australis* L. | Native | Annual | O |
| | *Euphorbia maculata* L. | Exotic | Annual | R |
| Fabaceae | *Kummerowia stipulacea* (Maxim.) Makino | Native | Annual | F |
| | *Trifolium pratense* L. | Exotic | Perennial | C |
| | *Vicia hirsuta* (L.) Gray | Native | Perennial | C |
| | *Vicia sativa* L. | Native | Perennial | A |
| Geraniaceae | *Geranium carolinianum* L. | Exotic | Annual | R |
| Iridaceae | *Sisyrinchium rosulatum* E.P. Bicknell | Exotic | Annual | F |
| Lamiaceae | *Lamium purpureum* L. | Native | Perennial | C |
| Oxalidaceae | *Oxalis corniculata* L. | Native | Perennial | C |
| Plantaginaceae | *Plantago lanceolata* L. | Exotic | Perennial | A |
| | *Veronica arvensis* L. | Exotic | Annual or Biennial | F |
| | *Veronica persica* Poir. | Exotic | Perennial | F |
| Poaceae | *Bromus catharticus* Vahl | Exotic | Annual | F |
| | *Dactylis glomerata* L. | Exotic | Perennial | O |
| | *Digitaria ciliaris* (Retz.) Koel | Native | Annual | F |
| | *Eleusine indica* (L.) Gaertn. | Native | Annual | C |

| Family | Species | Native or Exotic | Plant life-cycle | ACFOR scale |
|---|---|---|---|---|
| | *Elymus tsukushiensis* Honda var. *transiens* (Hack.) Osada | Native | Perennial | O |
| | *Festuca arundinacea* Schreb. | Exotic | Perennial | O |
| | *Festuca ovina* L. | Exotic | Perennial | O |
| | *Setaria pumila* (Poir.) Roem. & Schult. | Native | Annual | C |
| | *Setaria viridis* (L.) P. Beauv. | Native | Annual | A |
| | *Zoysia japonica* Steud. | Native | Perennial | R |
| Polygonaceae | *Rumex japonicus* Houtt. | Native | Perennial | O |
| Portulacaceae | *Portulaca oleracea* L. | Native | Perennial | F |
| Rubiaceae | *Galium spurium* var. *echinospermon* (Wallr.) Hayek | Native | Annual | R |
| Solanaceae | *Solanum carolinense* L. | Exotic | Perennial | R |
| Ulmaceae | *Zelkova serrata* (Thunb.) Makino | Native | Perennial | R |
| Vitaceae | *Cayratia japonica* (Thunb.) Gagnep. | Native | Perennial | O |