URBAN GREEN ROOFS PROMOTE METROPOLITAN BIODIVERSITY: A COMPARATIVE CASE STUDY

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Abstract

Urban green spaces can provide habitat and resources for urban dwelling fauna. Suburban green spaces occur most commonly as parks and roadside vegetation, but as human populations grow and space in cities becomes increasingly limited, space-efficient green solutions like green roofs and walls in metropolitan areas are becoming increasingly common. However, the efficacy of these forms of green infrastructure in attracting and promoting biodiversity remains limited. To address this, we compared arthropod, gastropod, and avian species richness and diversity between green and conventional roofs on neighbouring and identical buildings in metropolitan Sydney, Australia. By monitoring local biodiversity using motion sensing camera traps and regular insect surveys, we found that the green roof supported four times the avian, over seven times the arthropod, and twice the gastropod diversity of the conventional roof. Only the green roof attracted locally rare species including blue banded bees (*Amegilla Cingulata*) and metallic shield bugs (*Scutiphora pedicellata*). Our results suggest that green roofs, like other urban green spaces, can have ecological significance by attracting and supporting urban fauna that may then add important functional capacities to previously depauperate spaces. This study demonstrates the potential for the widespread adoption of green roofs to create more biologically diverse cities.

1. Introduction

The continued and rapid expanse of urbanisation poses a growing threat to biodiversity [1]. These threats notwithstanding, there has been an increasing trend in research initiatives aimed at understanding how best to conserve and promote biodiversity in areas where space is costly [2]. Perhaps counterintuitively, urban ecosystems are important refuges for novel species assemblages, sometimes housing both locally endangered native [3] and globally endangered introduced species [4]. The success of green spaces as an urban ecosystem in promoting biodiversity and providing habitat is dependent on their number, quality and connectedness [5]. Green spaces such as parks and roadside vegetation are common examples of important urban ecosystems [6], however, as human populations and building densities increase, so does the demand and competition for space. As such, various forms of green infrastructure, such as green roofs, green walls and other space efficient green solutions are becoming increasingly valued. While it is understood that residential and roadside vegetation provides important biodiversity functions, how green roofs shape urban biodiversity remains relatively understudied [7, Table 1].

Green roofs consist of diverse consortia of actively growing plants planted in soil or similar substrates above several layers of waterproofing, with various drainage and insulation systems beneath [8]. Green roofs are often acclaimed for their aesthetic appeal, however, they also provide quantitative ecological and economic benefits [9, 10], improved storm water retention [11], increased building energy efficiency [12], cooler microclimates [13] and potential habitat for fauna [14].

Green roofs can serve as habitat to a variety of insect species [16] and nesting habitat to shore and wading birds [17]. Plants species not initially planted have also been observed establishing on green roofs, likely as a result of avian and wind dispersal [18, 19]. Given the significant observational evidence of biodiversity atop green roofs, several studies have focused on attempting to quantify the biodiversity benefits of urban green roofs in comparison to conventional roofs, however, evidence remains equivocal, likely due to difficulty locating comparable roofs (Table 1). The development of a holistic understanding of how green roofs may support urban species is essential to understand how best to promote urban biodiversity, particularly with the increasing need for a developed knowledge of the conservation value of such spaces [7].

Here we aim to determine whether established green roofs have greater organism abundance and diversity than conventional roofs in Sydney, Australia. We compare a Biosolar roof, on which photovoltaic (PV) systems are integrated with a green roof, to a conventional roof containing only PV. We utilised a unique experimental design, where the presence of the green roof was the sole variable, with both study sites present in the same geographic location and of the same height, size, and shape. We assessed avian, arthropod, and gastropod diversity across both roofs utilising motion-sensing camera traps, at both macro- and micro-scales to quantify the biodiversity changes associated with the implementation of the green roof. Further, we monitored the vegetative community atop the roof, exploring plant succession and movement across the study period.

Table 1. Previously published literature on the biodiversity benefits of green roofs across several countries with varying climates and comparison types. Literature was gathered through a Google Scholar search for "Green roof biodiversity", following reference trails and prior knowledge of published literature.

Study	Country	Target Organisms	Comparison	Metric	Results
(Williams et al., 2014)[7]	Australia	*Review*	Green roofs & ground level green spaces	*Hypothesis testing*	Roofs can support similar biodiversity to ground-level habitats.
(MacIvor & Lundholm, 2011)[20]	Canada	Bees	Height of green roof	Nest Success	Height negatively impacted green roof nest success.
(Pearce & Walters, 2012)[21]	England	Bats	Roof type	Bat calls	More calls on green roof.
(Baumann, 2006)[17]	Switzerland	Birds	N/A	Presence/Absence	Organisms present
(Grant, 2006)[16]	England	Birds	N/A	Presence/Absence	Organisms present
(Berthon et al., 2015)[22]	Australia	Arthropods	Roof type	Diversity	2x Abundance 3x Diversity
(Dromgold et al., 2020)[23]	Australia	Arthropods	Green roof & ground level green spaces	Diversity	Abundance and Richness higher on ground-level habitats.
(Wang et al., 2017)[24]	Singapore	Birds/Butterflies	Roof type	Presence/Absence	Organisms present
(Pétremand et al., 2017)[25]	Switzerland	Beetles	N/A	Presence/Absence	Organisms present

2. Methods

2.1 Study sites

This study was conducted on two adjacent roofs atop recently constructed buildings in Barangaroo, in Central Sydney (-33.86479674708204, 151.20218101793557), which receives an annual rainfall of 1309 mm. The green and conventional roofs were constructed in 2019 and 2016, respectively. To the best of the authors knowledge, no two identical buildings where the sole difference is the presence of an extensive green roof, have previously been studied. The two buildings sit in an urban canyon, with minimal street trees and a single pedestrian park being the only nearby urban green space, with a direct sightline to Sydney Harbour. Both buildings are approximately 25 meters tall, and weather stations and pyranometers on each building demonstrated very little difference in abiotic factors between the two roofs, resulting in there being little-to-no confounding variables in relation to biodiversity within this study. Both the green roof and conventional roof are 1863.35 m^2, with 586.89 m^2 and 567.44 m^2 PV panel coverage, respectively (Figure 1). The green roof has a planted area of 1460.7 m^2 (78.4% total roof space), with PV panels covering 40.18 % of the planted areas. The study green roof was planted with a selection of native grasses and herbaceous plants (Table 2). The native plant assemblages were selected to be climatically adapted and to have the potential to attract endemic faunal communities to the roof. The green roof had a substrate depth of 120 mm and was irrigated with below-ground hoses on a timer.

Table 2. The vegetative community planted atop the green roof. Asterisks indicates species not native to Australia.

	Botanic name	Common name
Open areas	*Dianella caerulea*	Blue flax-lily
	Myoporum parvifolium	Creeping boobialla
	Brachyscome multifida	Cut-leaved Daisy
	*Gazania tomentosa**	Silver leaf gazania
	Goodenia ovata	Hop goodenia
	Poa poiformis	Coastal tussock grass
	Themeda australis	Kangaroo grass
	Carpobrotus glaucescens	Pigface
Shaded areas	*Viola hederacea*	Ivy-leaved violet
	Dichondra repens	Kidney weed
	*Mesembryanthemum cordifolium**	Baby sun rose
	*Crassula multicava**	Fairy crassula
	Dianella caerulea	Blue flax-lily

2.2 Biodiversity monitoring

From August 2020 to June 2021, avian, gastropod, and arthropod communities visiting the green and conventional roofs were monitored using motion-sensing camera trap arrays. Each roof featured a mirrored design using four cameras set, monitoring the entirety of each roof (Figure 1; Strike Force Pro XD, Browning Trail Cameras, USA). Cameras were set to capture a single image when motion was detected, with a 1-second interval set before retriggering. Cameras were set up at predicted biodiversity hot spots on the green roof (i.e., focused on locations with high vegetation), and the corresponding position on the conventional roof. Flora was maintained fortnightly by maintenance workers to prevent plant growth reducing light availability for the PVs. As such, height was not an accurate metric for the growth of plant species for the duration of the study. To ensure that patterns of biodiversity were not driven by bioclimatic differences between the two roofs, temperature loggers (i-Button model DS1921G) were installed to monitor the micro-climate air temperature and humidity as well as macro-climate variables such as wind speed, direction, rainfall, and light intensity using portable weather stations (HP2551, Ecowitt, USA), and building weather stations/pyranometers.

Figure 1. Map of the Biosolar roof. Black denotes areas of open vegetation, white denotes areas occupied by HVAC infrastructure, grey (from left to right) denotes the building maintenance unit and a large, open rocky area, small panels denote solar panels and yellow denotes a preinstalled "bee hotel". Camera traps are marked with an 'x' and red arrows show the orientation of the cameras. Conventional roof is identical, except vegetation areas are concrete.

Additionally, the green roof was constructed with a native bee hotel. The hotel mimicked natural nest locations used by indigenous bee species and is aimed at attracting a diverse range of endemic bees to establish nests within them. Additional bee hotels (Native bee sanctuary kit, Mr. Fothergills, Australia) were deployed on each roof to monitor their performance in attracting fauna.

Monitoring arthropod diversity with camera traps can prove difficult if an individual is not immediately in front of the lens of the camera, given the coarse image quality. Understanding this, a camera trap was established on both roofs to monitor the bee hotels exclusively. Bee hotel cameras shared settings with the other cameras. All bee hotels failed to attract any bee species. Hotels were quickly occupied by leopard slugs (*Limax maximus*) on the green roof and remained unoccupied on the conventional roof. In conjunction with camera traps, manual insect surveys were conducted approximately once a fortnight. Photos of each animal detected were taken during the survey, and images identified with the help of field guides and experts. Surveys were unable to be conducted at night due to building security protocols, potentially excluding predominantly nocturnal insects from the surveys.

2.3 Data analysis

To compare differences in species diversity between the green roof and conventional roof, avian, arthropod, and gastropod richness and abundance data were used to calculate the Shannon-Wiener, Simpsons, Mehniks and Margalefs diversity indices. Metrics were calculated with avian, arthropod, and gastropod species combined and separately to determine which taxon assemblages displayed the most dissimilarity between the green and conventional roof. We created a species accumulation curve to estimate the rate of species observation compared to survey effort for both the green and conventional roof. Diversity and richness metrics were all calculated using the ‘vegan’ package in R (Version 3.6.3 [26]).

3. Results

3.1 Faunal Biodiversity

Species richness was higher on the green roof compared to the conventional roof. Four bird, two gastropod and 26 arthropod species were observed on the green roof compared to one, zero and three on the conventional roof, respectively (Figure 2C, Supplementary Figure 1). Throughout the study period, we observed zero gastropod species on the conventional roof, but considerable numbers on the green roof, all of which were the common garden snail (*Cantareus aspersus*) and leopard slug (Supplementary tables 1 & 2). Over the course of the monitoring period, the green roof was host to significantly more diverse fauna (Shannon-Wiener diversity index 3.39 versus 1.61 for the green and conventional roofs respectively, Figure 3, supplementary table 3). A full species list can be found in Supplementary table 1.

Bioclimatic variables were similar on the green and conventional roofs, as expected given their close proximity. Ambient air temperatures were similar on the green roof and conventional roofs, with the average annual 7am-7pm temperatures being 20.9 °C and 21.5 °C respectively with an average relative humidity of 62.13% on both roofs. Prevailing wind direction and speed on the green roof was 3.65° and 4.74 km/h, while on the conventional roof it was 6.26° and 3.97 km/h, which indicates a slight reduction in windspeed as it moves through the urban canyon.

3.2 Vegetation community

There was evidence of substantial changes within the plant community of the shaded areas (Table 3). From the commencement of the study *Mesembryanthemum cordifolium* (syn. *Apentia cordifolia*) rapidly increased its vegetative cover underneath the PV panelling. *M. cordifolium* was present in 6% of shaded spaces upon initial planting (2019), however by the commencement of the study (2020), *M. cordifolium* covered approximately 55% of all shaded areas (beneath the PV panelling), including areas that were unplanted upon roof construction. Area covered by this species increased to 85% by the end of the study period (2021). While the shaded plant community below the PV panels was dynamic in nature, we observed close to no noticeable changes in the community composition in the open areas.

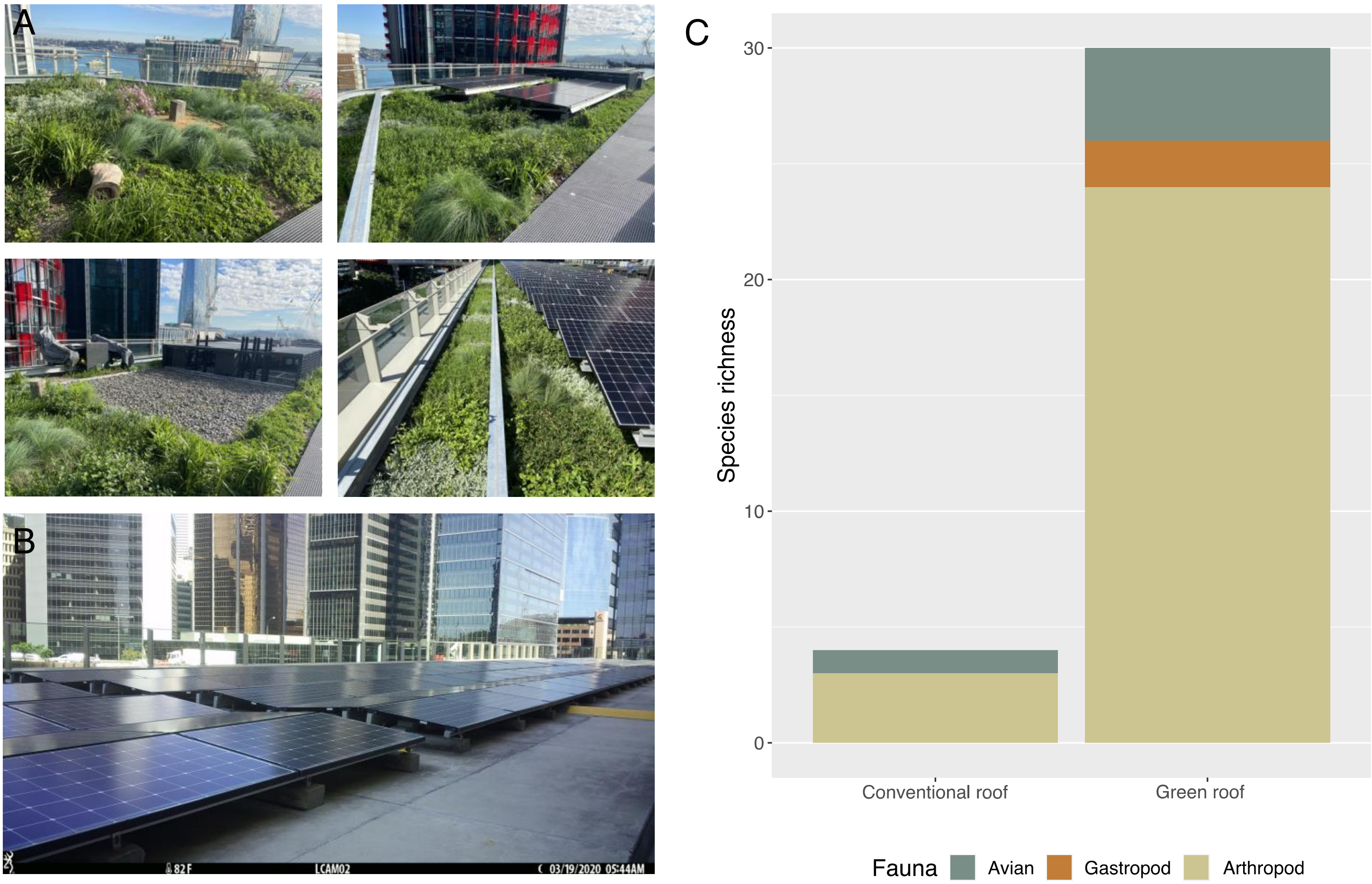

Figure 2 A – Images of the four major vegetated sections of the green roof. B – Image of the Conventional roof. C – Richness of avian, arthropod, and gastropod communities atop the Green and Conventional roofs taken from camera traps and surveys.

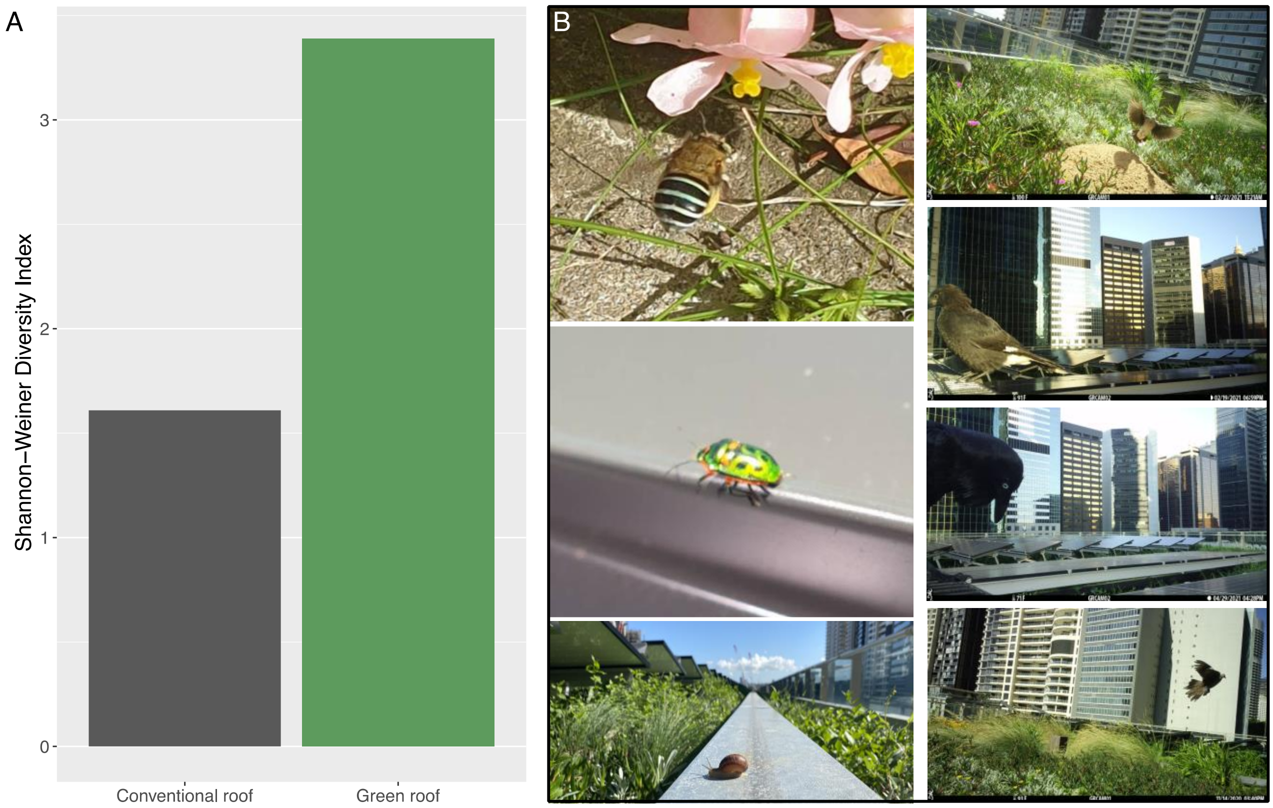

Figure 3 A - Shannon-Weiner Diversity Index for combined avian, arthropod, and gastropod communities atop the green and conventional roofs; B - Examples of faunal diversity (clockwise from top left) – blue banded bee (*Amegilla Cingulata*), spotted dove (*Spilopelia chinensis*), juvenile Pied currawong (*Strepera graculina*), Australian raven (*Corvus coronoides*), spotted dove, garden snail (*Cantareus aspersus*), metallic shield bug (*Scutiphora pedicellata*).

Table 3. Initial and seasonal percentage plant cover (estimated) for the entirety of the green roof. Initial coverage of shaded areas (beneath PV panelling) was 88 % as not all spaces were planted. Plant succession led to the cover of these areas by Winter.

	Botanic name	Initial planting	Spring cover	Summer cover	Autumn cover	Winter cover
Open areas	*Dianella caerulea*	12.5%	12.5%	12.5%	12.5%	12.5%
	Myoporum parvifolium	12.5%	12.5%	12.5%	12.5%	12.5%
	Brachyscome multifida	12.5%	12.5%	12.5%	12.5%	12.5%
	Gazania tomentosa	12.5%	12.5%	12.5%	12.5%	12.5%
	Goodenia ovata	12.5%	12.5%	12.5%	12.5%	12.5%
	Poa poiformis	12.5%	12.5%	12.5%	12.5%	12.5%
	Themeda australis	12.5%	12.5%	12.5%	12.5%	12.5%
	Carpobrotus glaucescens	12.5%	12.5%	12.5%	12.5%	12.5%
Shaded areas	*Viola hederacea*	35%	25%	20%	15%	10%
	Dichondra repens	35%	10%	10%	5%	5%
	Mesembryanthemum cordifolium	6%	55%	65%	80%	85%
	Crassula multicava	6%	5%	3%	0%	0%
	Dianella caerulea	6%	5%	2%	0%	0%

4. Discussion

Here, we provide a unique case study that clearly demonstrates the potential for green roofs to promote biodiversity in urban spaces. The green roof within our study supported four times the avian and over seven times the arthropod diversity, as well as providing a gastropod habitat, not present on the conventional roof.

The green roof used for this study was constructed with the aim of promoting biological diversity, and this has demonstrated some success, supporting an eclectic ecological community, and providing refuge to many native and non-native species. A diverse group of native and introduced plants were selected (Table 2) to attract a range of pollinators to the green roof, and this was successful in attracting a high level of arthropod diversity. The roof also attracted a few rare and unexpected arthropods in the form of blue banded bees (*Amegilla Cingulata*) and metallic shield bugs (*Scutiphora pedicellata*).

The green roof also supported a significantly higher level of avian diversity than the conventional roof. Around the globe, birds have been shown to use green roofs to hunt prey, as habitat and as locations to build nests [27]. Our results suggest that green roofs support urban avian biodiversity, aligning with previous work that has highlighted that urban green spaces are locations of significant conservation value [16, 17]. All avian species present on the green roof were urban adapted and relatively common throughout Sydney. Green roofs have been found to typically provide habitat and foraging opportunities to urban species, rather than attracting new ones [24]. Additionally, we detected evidence of intraguild predation on the roof. A deceased noisy miner (*Manorina melanocephala*), a species not found alive in the sampling period, was found beneath the PV panels. The bird had its head removed and most of its organs consumed. As there was no evidence of mammalian scavengers, this suggests that the bird had been eaten by an avian predator or scavenger. Unfortunately, this event was not documented by the camera traps. Regardless, this predation event suggests that the green roof attracted more avian biodiversity than presented within our results and provided habitat and hunting opportunities to birds of prey. With this in mind, the widespread implementation of green roofs may facilitate the urban recolonisation of birds of prey.

The vegetation community atop the green roof attracted a diverse invertebrate community. Vegetation like *Dianella caerulea* and *Viola hederacea* attracted pollinators to the roof, highlighted by the high frequency of European honeybee (*Apis mellifera*) and blue banded bee observations. As was the case with the avian community, all invertebrates present on the roof were urban adapted species. The vegetative community was itself dynamic throughout the study period. Changes were primarily dominated by the growth of *M. cordifolium,* which colonised most of the shaded sections beneath the PV, outperforming the previously dominant *Viola hederacea* which was responsible for much of the vegetative cover beneath the PVs at initial planting. However, the vegetation community in the open areas of the green roof were relatively stable, with no discernible change in the community's composition noticed. This section of vegetation was subject to more intense and regular maintenance possibly hindering changes in the plant community. Previous studies have reported that shading on green roofs may promote plant diversity and richness [28], however, this study provides evidence that shaded areas can become dominated by a select few species.

Given the height of the green roof, it is possible that this was a barrier to the establishment of many arthropod and avian species [20]. This suggests that future green roof locations may benefit from being located closer to the ground. The green roof was very young, having been established only months prior to the commencement of our study. Previous work has highlighted that green roofs reach their peak biodiversity approximately two years after their establishment [29]. Given this, it is likely that the green roof will only become more diverse into the future. It is also important to note that biodiversity atop both roofs may have been higher than recorded within the study. To not interfere with, harm, or reduce the diversity of roof top inhabitants, we chose to use non-lethal methods to assess diversity. Insect diversity is commonly assessed with traps that remove individuals from the population [20], directly reducing species richness and abundance in the process. Whilst our regular insect surveys coupled with camera traps monitoring bee hotels were sufficient to quantify the benefits of green roof implementation, diversity is likely to have been greater than estimated.

5. Summary and Conclusion

Urban green spaces serve as important ecological refuges, promoting ecological diversity in human dominated spaces [6]. However, evidence for the role of green roofs in urban biodiversity conservation has remained equivocal [7]. Here, we clearly demonstrate, with a unique case study, that green roofs can attract and support significantly higher biodiversity than conventional roofs, suggesting that green roofs are important ecological refuges in urban areas. The widespread adoption of green roof initiatives, coupled with the promotion of urban green space initiatives is likely to create wilder, more biologically diverse cities.

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