# Islands in the sky, urban biodiversity enhancement in NZ on indigenous living roof landscapes

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ABSTRACT: This paper analyses the habitat opportunities provided by the new landscapes of living roofs in the New Zealand (NZ) context. The paper identifies vegetative design considerations for future potentials in urban biodiversity enhancement.

Lack of local information and experience has been a barrier to living roof development in NZ. In response, the first corporate extensive living roof using only New Zealand indigenous plant species was initiated and completed a-top the Waitakere City Council (WCC) building in winter 2006. Plant species suitable for living roofs need to be low-growing and adapted to the special environmental conditions. Sedums are the norm on overseas roofs. The aim for the Waitakere roof was to find native alternatives. A range of indigenous plant species have and continue to be trialed on the roof and results monitored.

Monitoring of this project since its completion has provided important data on the potential of indigenous flora within living roofs and has confirmed that NZ indigenous plants can survive on an extensive living roof but that some are more resilient to the conditions than others. The results have established a range of considerations for successful use of NZ indigenous plants on living roofs, both horticultural and aesthetic.

Insect abundance and diversity is also being quantified using methods suited to windy environments and low-stature vegetation (a first for NZ living roofs), results showing that a range of native and exotic insect species are making the living roof their home with a surprisingly diverse fauna.

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## 1.0 INTRODUCTION

NZ's landscape heritage is inextricably linked to the concept of an islanded nature. Not only has its distinctive flora and fauna been determined by our ancient Gondwanaland separation, but the subsequent history of biodiversity reduction and extinction through habitat loss by human settlement and predation/competition from invasive species has instigated a conservation tradition focused on protective enclaves situated within predator free offshore or fenced mainland islands.

Such conservation concepts are limited in their ability to address biodiversity loss in our urban environments. Living roofs offer an opportunity to bring the conservation island concept into a contemporary context integrated within our urban landscapes. This would see the once neglected and un-used landscape realm of buildings creating biodiverse islands of indigenous flora which may even hold potential for conservation of rare lizard and insect species. Living roofs can therefore be permanent reservoirs for less common local species and/or extend the area of habitat within urban environments for both native and exotic invertebrates.

The importance of living roofs to the discipline of architectural science has focuses on how they can contribute in mitigating negative impacts of buildings within the urban environment (Oberndorfer et al, 2007). Roofs in our cities can make up a significant portion of a buildings' overall surface and can be up to 32% of the horizontal surface within an urban environment (Frazer in Oberndorfer et al 2007). Living roofs are documented as assisting in reducing building energy consumption, increase sound insulation, fire resistance, longevity of the roof and play a role in stormwater management, air-quality improvement and reduction of urban heat island effect (Dunnet, Kohler, Porsche and Getter in Oberndorfer et al 2007). The potential of living roofs to also reflect indigenous sense of place and contribute to urban biodiversity is yet another contribution that can be made. In NZ, this potential is only just beginning to be explored, but as this paper will outline, the results to date are promising and there are a range of design responses which those involved in NZ building design and specification can implement to enhance the indigenous biodiversity potential specific to our unique flora and fauna.

Using the case study of the first indigenous extensive living roof in NZ in Waitakere, this paper outlines the key learnings from the first four years of the WCC living roof since its implementation and identifies a range of design strategies useful for Auckland living roof projects to enhance their potential to achieve biodiversity to enrich the urban environment as ‘islands in the sky’.

The key elements of the biodiverse living roof are vegetation and invertebrates. These two core elements then influence and invite a broader range of fauna potentials. At the WCC living roof, vegetation and invertebrate elements have formed the basis of the biodiversity monitoring to date.

### 1.1 The role of plants on living roofs

In most extensive living roofs the primary role of the plants is to ensure the surface is stable – resistant to rain, wind and animals. Stems and leaves physically protect the surface from impact while roots bind and hold the substrate in place. Plants also provide up to 40% of the attenuated stormwater volume through intercepting rain and through evapotranspiration – this also cools the air above green roofs. A dense, self-repairing plant cover is therefore usually highly desirable. However, from an ecosystem perspective, plant cover is likely to be discontinuous or patchy on flat or gently undulating roofs designed to enhance invertebrate and bird biodiversity, particularly where the ecosystems being mimicked are ruderal (urban ‘wastelands’) – as some species of invertebrates, birds and lizards require areas that are sparsely vegetated or bare. As such, determining the desired level and type of vegetative cover for the intended multiple roles that vegetation plays in a living roof system is an important key design decision.

Unlike most gardens, visual appearance is usually secondary to the functional role. Plants first have to survive in shallow substrate and droughty, fairly hostile environment, so the list of potential plants for extensive living roofs is relatively short, particularly in the absence of irrigation and regular fertilisation. Aesthetic values have greatest importance if the roof is able to be viewed – generally the closer the view, the more important visual appearance.

### 1.2 The role of insects on living roofs

Living roofs can be important habitat for animals ranging from insects to lizards and birds, including endangered species. Extensive living roofs, generally 150mm or less deep (Peck in Burgess, 2004) are particularly valuable as habitat as they are not designed to support people and so are rarely disturbed.

Nearly all research on living roof invertebrates is recent (published post-2000). Until 2007 there had been no studies of NZ living roof insects; however, relevant NZ studies include investigations of insect colonization of bare and revegetating areas in mines (Simcock et al 1999, Curtis et al. 2000), farms (Crisp et al. 1998, Reay and Norton 1999) and urban areas other than forest remnants (Toft et al. 2004).

## 2.0 THE WAITAKERE CITY COUNCIL LIVING ROOF CASE STUDY

### 2.1 Concept for WCC living roof

The area of the WCC living roof is 500 $m^2$ with a weight capacity of 230 $kg/m^2$ (Davies, 2007). The vision for the WCC living roof was to:

- Demonstrate the range of sustainable benefits of living roof technology.
- To create a green roof which is specific to the NZ situation and at least in part, reflective of plant species found in the Waitakere environment.
- To create an organic patchwork of plants which will move and change over the years with competition and natural growth styles.
- To provide splashes of colour variation through leaf colour, texture and seasonal flowering.
- To ensure a multitude of outcomes are achieved for stormwater, habitat and amenity.
- To provide a robust, well-researched and documented process for plant selection, including substrate make-up, and monitoring to provide useful and innovative input into green roof technology specific to NZ.

### 2.2 Identification of potential native plants for the WCC living roof

Plant selection for the WCC living roof began with the identification of the environmental conditions which might harbour the most appropriately adaptive plants for the living roof environment.

Low mat-forming or cushion-forming plants naturally found in harsh, exposed, droughty environments with limited rooting depth were targeted as being potentially suitable for extensive living roofs. These included plants of cliffs, saline environments, dry turfs and more recently, alpine and scree environments. In cities, plants naturally exploiting old rock walls were targeted, especially the harshest sites, i.e. north to west aspects with little shade and very limited rooting depth near the top of a wall. Plants that tolerate droughts by storing water in above-ground tissues (succulents, e.g., *Disphyma australe*, which also have thick waxy cuticles to reduce water loss) are common on extensive living roofs, as are species that can utilize a Crassulacean Acid Metabolism (CAM) for photosynthesis. Sedums and Crassulas are CAM plants that are able to store carbon dioxide in their leaves during dark, cool hours; they can then close their stomata during daylight (photosynthetic) hours, reducing moisture loss. Tussocks have been successful on roofs around the world, with the adaptations of rolled leaves that reduce water transpiration losses, water harvesting, and extensive root systems. Many living roof plants have leaves with fine hairs or a waxy coating that gives them a grey or silver appearance.

Not all plants that are adapted to these harsh environments were considered suitable for the WCC living roof. Plants growing on rock faces can often have very long and extensive root systems that exploit fissures to access water and maintain cool root runs with limited competition from other plants – these are unsuitable for fully vegetated green roofs, especially those underlain by materials with high thermal mass. Likewise, many sand dune plants that tolerate drought by having extensive root systems or large tubers (especially tap roots) may not be suitable for green roofs.

Plant structure was also considered important – living roofs can be extremely windy places (Dunnett and Kingsbury, 2004), especially on taller buildings, and where wind is deflected or accelerated by adjacent hard surfaces (e.g., wind-tunnels). As such, the WCC living roof plants were generally less than 300 mm height. Suitable plants will either have a fine leaf structure that disperses wind (e.g., *Poa* grasses and *Festuca* tussocks, *Libertia* iris), a compact form of tightly bound interlocking branches with small leaves (e.g., prostrate *Coprosma* and *Pimelea*, and *Muehlenbeckia* species) or are anchored at internodes, e.g., *Selliera radicans, Disphyma australe, Acaena* and *Leptinella* species.

### 2.3 WCC plant list

The following plant list identifies the native plant species which have been trialled on the WCC living roof. It highlights those which have proven to be most suitable for this lightweight (100–300 mm depth) non-irrigated living roof. Continual trialling of new species is being undertaken. Images of nearly all the plants can be seen on the New Zealand Plant Conservation Network (www.nzpcn.org.nz).

**Table 1: WCC Living Roof Plant Species Trialled**

| Plant Species | Natural Environment | Year first planted on roof | Present in July 2010 | Success (1 being most successful 5 being least) | Comments |
|---|---|---|---|---|---|
| *Acaena microphylla* | | Aug 2006 | | 5 | |
| *Anaphalioides bellidioides* | | Aug 2006 | | 5 | |
| *Astelia banksii* | Rocky cliffs<br>Coastal | June 2009 | √ | 2 | |
| *Calystegia soldanella* | Coastal | July 2007 | | 4 | |
| *Coprosma acerosa* | Coastal | Aug 2006 | √ | 2 | |
| *Dichondra repens* | Coastal | Aug 2006 | √ | 3 | |
| *Disphyma australe* | Coastal | Aug 2006 | | 5 | Died after 2 years from extensive fungal disease. Replanted and did not survive. |
| *Festuca coxii* | Rocky cliffs<br>Coastal | 2006 – present | √ | 1 | Most successful plant species to date |
| *Haloragis erecta* | Coastal<br>Disturbed land | June 2009 | √ | 3 | |
| *Haloragis erecta* 'Wellington bronze' | Coastal<br>Disturbed land | June 2009 | √ | 3 | |
| *Hebe obtusata* | Coastal<br>Rocky cliffs | June 2009 | √ | 1 | |
| *Hebe pimeleoides* subsp. *faucicola* | Coastal | June 2009 | √ | 5 | |
| *Hibiscus diversifolius* | Coastal | June 2009 | | 5 | |
| *Hibiscus richardsonii* | Coastal | June 2009 | | 5 | |
| *Leptostigma setulosa* | | Aug 2006 | | | |
| *Libertia peregrinans* | Coastal<br>Lowland | Aug 2006 | √ | 2 | |
| *Muehlenbeckia complexa* | Coastal | Aug 2006 | √ | 3 | |
| *Pimelea prostrata* | Coastal | Aug 2006 | √ | 3 | |
| *Pimelea* aff. *Urvilleana* | Coastal | July 2010 | | 3 | |
| *Plantago triandra* | | June 2009 | √ | 3 | |
| *Raoulia hookerii* | Alpine | June 2009 | √ | 2 | |
| *Raoulia parkii* | Alpine | June 2009 | √ | 2 | |
| *Rubus cissoides* | Alpine | June 2009 | | 5 | |
| *Scandia rosifolia* | Alpine | June 2009 | √ | 4 | |

Source: (Author 2010)

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**Figure 1: The WCC Living in May 2010 (autumn) showing the diversity of plant growth forms from tussocks (*Festuca coxii*) and spikey orange irises (*Libertia peregrinans*) to tangled ground covers along the right-hand parapet (*Muehlenbeckia* spp) and dense mounds of Hebe (*Hebe obtusata*).**

## 3.0 INVERTEBRATE BIODIVERSITY OF THE WAITAKERE CIVIC CENTRE LIVING ROOF

### 3.1 Aims

The invertebrate research for the WCC living roof has three aims:

- To compare and develop methods for monitoring invertebrates on extensive living roofs.
- To quantify the abundance and diversity of native and exotic invertebrates as extensive living roofs develop to a near-complete vegetation cover. An important part is to understand how the invertebrates reached the roof and their roles in living roof ecosystems.
- To assess the potential for extensive living roofs to be city refuges for native fauna, and which native fauna could be targeted, e.g., stick insects, burrowing bees, butterflies, flightless beetles, skinks, and geckos.

### 3.2 Methods

The invertebrate fauna of the WCC living roof is being assessed over 3–4 years, over which time a relatively stable plant cover and leaf humus layers, important invertebrate habitat, are expected to have established. Monitoring extensive roofs from early in vegetation establishment requires use of equipment resistant to high winds but needing minimal anchoring, as pegs or stakes cannot be used to keep equipment on the roof. The monitoring methods used to date include installing wooden refugia, pitfall trapping, emergence trapping, and ant baiting.

### 3.3 Results

A total of over 1500 invertebrates were collected in the first year of monitoring. Spiders were the most common inhabitants found under the wooden discs, especially two species of South African *Steatoda* spiders (known as "false katipos" in NZ) and a wolf spider (probably the common native *Anoteropsis hilaris*). Egg masses of *Steatoda* were particularly common. Other arachnids encountered included the common European harvestman (*Phalangium opilio*) and mites. Spiders are known to colonise all manner of environments very quickly, with some able to survive very barren areas feeding on the insect wind drift. Beetles, weevils, millipedes, and centipedes were also found beneath the pine discs, and again these seem to be introduced rather than native varieties.

A range of introduced molluscs, including at least 3 species of slugs and 2 species of snails were found. It is highly likely that these arrived with the plants from the nurseries. The national distribution of two of the slugs is strongly associated with plant nurseries. This emphasizes the importance of good pest management and nursery hygiene practices as slugs will negatively impact on the plant health by eating young seedlings and occupy niches that might have been useful to native species.

The most abundant invertebrate order in the emergence traps were Diptera (flies), the majority of these were very small varieties such as Sciaridae, Cecidomyiidae, and Phoridae, which are very abundant in planted situations and include a number of adventive species Most likley introduced by people. Common introduced pasture flies from the Agromyzidae and Ephydridae were also well represented in the samples. More encouraging was the collection of 8 native crane flies (*Limonia aegrotans*) in 4 of the living roof emergence traps. It is quite likely that these flies were brought to the roof as larvae in the soil with the plants.

Seven small moths were collected in the samples. Four of these were *Bedellia psamminella*, whose caterpillars are known to feed on Mercury Bay weed, one of the plants grown on the roof. This moth is considered indigenous in NZ, but occurs widely around the world. Other moths included the abundant introduced dusky scuttler (*Opogona* *omascopa*); another common introduced Australian species (*Phrissogonus laticostatus*) that feeds on the flowers of Asteraceae; and common native detritivorous species (*Trachypepla* sp.).

The ant species were *Iridomyrmex* and *Paratrechina* species, common adventives in the Auckland region. The bugs (Hemiptera) have not been processed to identification at this point, but were mostly ground bugs (Lygaeidae) with a few aphids.

Source: (Authors 2010)

**Figure 2: From left to right: The caterpillar (wooly bear) and moth of Magpie moth, *Nyctemera amica and N. annulata* (Arctiidae), an eleven-spotted ladybird (*Coccinella undecimpunctata*) on iceplant.**

As is the case in most terrestrial habitats, the most numerous invertebrate groups were mites (Acari) and springtails (Collembola), which together accounted for over 80% of the catch in the emergence traps. These, and a number of other groups, were far more abundant in the living roof traps than on the bare control roof.

Bugs (Hemiptera) were relatively numerous but consisted mostly of early instar ground bugs and a few aphids. The ant fauna collected in pitfall traps consisted of one common native species (*Monomorium antarcticum*) and 4 common introduced species (*Paratrechina* sp.; *Tetramorium grassii*; *Monomorium fieldi*; and *Iridomyrmex* sp.). Two species of beetles were collected in pitfall traps, both are adventive. One is a small weevil (*Dryophtyhorus* sp.) and the other is an Australian species of ground beetle (*Lecanomerus atriceps*). Whereas the majority of native ground beetles are flightless and would require translocation on to the living roof, this Australian species is a very good flier and would have found its own way on to the roof.

### 3.4 Additional observations

The day-flying Magpie moths (*Nyctemera annulata-amica*) were observed on the roof with their "wooly bear" caterpillars feeding on self-seeded common groundsel (*Senecio vulgaris*). The magpie moths in the Waitakere area tend to be a hybrid between the Australian *amica* and the native *annulata*. The introduced honeybee (*Apis mellifera*) and bumblebees were active on the roof when *Selliera radicans*, NZ iceplant (*Disphyma australe*) and NZ daphne (*Pimelea prostrat*a) were flowering. A bagmoth case (a native moth, *Liothula* species) was found on sand dune coprosma (*Coprosma acerosa*) – the caterpillar lives in the case. Jumping spiders (*Euophrys* sp.) were also occasionally seen.

Source: (Authors 2010)

**Figure 3: Introduced honeybees (*Apis mellifera)* on NZ Daphne and iceplant, summer 2007/2008**

The invertebrate community on the green roof is strongly biased towards adventive species, which is typical of degraded urban habitats in NZ. The natives that occur are some of the most ubiquitous species that have adapted well to anthropogenic habitats (created and/or caused by humans). The living roof is providing habitat for insects and allowing populations of invertebrates to establish and survive. However, in term of native invertebrates, it is not providing significantly (as would be expected at this early stage) to the enhancement of biodiversity in the city. However, now that the baseline survey is complete, we can monitor changes in the invertebrate community over time.

With appropriate development and introductions, the living roof could provide permanent habitat for a range of flightless native invertebrates that otherwise struggle to survive in an urban environment where introduced rodents prey on them, introduced invertebrates compete with them, and roads and pavements are too inhospitable for them to move across. This might include animals such as weta, via establishment of weta (Hemideina) refuges (Trewick and Morgan-Richards, 2000) and relatively rare creatures such as some of the large native ground beetles (Carabidae).

The living roof at WCC also provides a local opportunity to promote native butterfly populations, which have declined significantly over the years. Muehlenbeckia, one of the plants used on the roof garden, is the primary food plant for several native copper butterflies (*Lycaenidae*), as well as some interesting moths. The secure nature of living roofs also makes them potential sites for breeding the colourful admiral butterflies, whose caterpillars favour nettles that may be inappropriate for planting in more accessible settings. Nettles could be established in areas where afternoon shade, increased moisture supply and/or a deeper substrate can be assured.

## 4.0 DISCUSSION

### 4.1 Habitat opportunities for NZ living roofs

The research undertaken to date on the WCC living roof indicate a range of ways biodiversity values of living roofs could be enhanced and design strategies put in place to increase biodiversity values and vegetative success.

**Figure 4: Mound (identified by black circle) created on WCC living roof showing different plant species able to survive in the deeper soil and shading opportunities provided by the taller plants and the associated micro-habitats.**

**Table 2: Design Considerations for NZ Living Roofs**

| NZ (in particular Auckland) Living Roof Design Strategies | Issues Addressed |
| --- | --- |
| ***Moisture and Irrigation***<br>Addition of additional moisture storage opportunities through use of drainage layers which incorporate water holding cups.<br><br>Addition of under surface irrigation for extreme summer drought periods for those roofs with no moisture storage opportunities in drainage layers.<br><br>Strategic irrigation to enhance the growth and area covered by *Muehlenbeckia* species to increase the habitat for copper butterflies. | Severity of summer moisture stress. Moisture stress is determined by substrate depth, moisture storage, underlying thermal mass, duration and timing of shade, wind exposure (including discharges from air conditioners), roof aspect and local climate.<br><br>Risk of poor plant growth is also reduced by providing irrigation, particularly over the first summer or if plants are being established in unfavourable times of the year when they are more likely to be stressed or in a reproductive rather than vegetative state (late spring through early autumn). |
| ***Microclimate***<br>Creation of mounds and differences in substrate depth across a roof. | A shallow substrate can only support (anchor) low-growing plants. Taller plants can be accommodated by adding deeper substrate through mounding over structural supports or as tree pits, and individual plants may need to be anchored to the surface.<br><br>Mounding creates opportunity for microclimate development on the roof, by creating areas of different shading and moisture retention. |

| NZ (in particular Auckland) Living Roof Design Strategies | Issues Addressed |
|---|---|
| ***Plant Density***<br>Ensure the plant palette includes a high proportion of species that provide a moderate to rapid cover (e.g., 75% cover within 2 years for a flat roof), and relatively few species that are slow-growing. The latter may be clustered near access points to allow more regular maintenance.<br><br>Four key strategies reduce the risk of poor plant establishment or growth: using a variety of species including plants that spread or seed into gaps; a minimum 100-mm depth of substrate (preferably with some localized increases to 150 mm) | Plant cover established quickly. |
| ***Plant Sizes***<br>In New Zealand most green roofs are established using plugs or small root trainers. Large plants, (e.g. PB2 or 3) should generally not be used, except on deeper roofs and as sparse planting for instant visual impact. Strategic clustering of smaller plants and use of contrasting mulches can also achieve this. Consider growing larger plants in green roof substrates as the standard propagation mixes have a very high organic component that is susceptible to shrinkage over time, may increase the weight of the roof, and will reduce or slow root exploration into the green roof media. A few New Zealand growers can supply pre-grown mats. | Successful establishment. |
| ***Substrate Selection and Preparation***<br>Ensure organic components of substrate are heat-treated (composted), and supplying quarries should be free of weeds, particularly pampas. Some biodiverse roofs may deliberately use local soils to make use of local seed burdens, as may (heavy) roofs that are designed to blend roof vegetation into the landscape (e.g., tussocks and pasture).<br><br>Some plants are available in a variety of forms and leaf sizes. The most prostrate and dense forms are generally preferred for green roofs as they are less susceptible to collar rock and are lower maintenance (as they suppress weeds)<br>Some species have many available varieties and cultivars, e.g., manuka, coprosma, NZ iris (Libertia). Plants sourced from exposed, droughty sites, are more likely to perform well, as are the least 'bred' forms | Minimisation of maintenance (i.e. weed removal) during establishment. |
| ***Refugia (artificial and natural)***<br>The addition of wood, like the refugia or weta roosts, increases the diversity of habitats available, and establishment of specific plant species (e.g., nettles for Admiral butterflies), or in the case of the magpie moth, avoiding weeding host *Senecio* plants can enhance specific native invertebrates. Biodiversity values can also be increased by introducing invertebrates, e.g. successful introduction of native cricket and earthworm populations could allow skinks to be introduced to the vertebrate-free roof. | Lack of shelter and key environmental conditions for success of particular native fauna. |
| ***Maintenance***<br>A 'construct and maintain' contract with the living roof construction company/landscape architect of a minimum 18-month duration (two growing seasons) and budget for monthly visits or interrogations during the first 6 months, then quarterly visits, will also help early identification and fixing of potential problems. A maintenance contract is ideally linked to a person on site who will observe the roof on a weekly or fortnightly basis, especially during summer when timing of any supplementary irrigation may be important to ensure plant survival. | Successful establishment and risk management. |

## CONCLUSION

The results of the vegetation and habitat monitoring of the WCC living roof up to 2010 show that roofs such as this slowly develop unique and relatively biodiverse (native and exotic mixed) habitats which could be further enhanced as ideal sites for native insects, bird visits and vertebrates such as skinks. This is possible as they are not walked on by people, represent new habitat, and are unlikely to have the pest mammal issues that the more ‘terrestrial’ habitats have.

At this early stage, relatively few native invertebrates are inhabiting the WCC living roof. However, there are many ways biodiversity values of the living roof could be enhanced through specific design decisions.

The modifications to the WCC living roof environment made over the last three years (including many of the strategies outlined in Table 2, such as mounding, installation of irrigation for drought periods, incorporation of specific habitat improvement for target native species) alongside biodiversity monitoring has provided insights into a range of design responses which can further enhance the potential for living roofs in Auckland to be biodiverse habitats.

> As noted by Obendorfer (2007), living roofs function as biological systems, and the interaction of the organisms that inhabit them represents a frontier in applied ecology and an opportunity to put interdisciplinary research into practice at the interface between constructed ecosystems and the greater urban environment”.

The research being undertaken at the WCC living roofs aims to explore this urban biodiversity role in a specifically NZ context. Living roofs in NZ can and should go beyond building sustainability issues (stormwater and insulation) and provide a viable urban opportunity to establish a network of islands in the sky, vital areas of native biodiversity and protective areas for rare and endangered flora and fauna – embedding the New Zealand island conservation tradition into our urban landscapes.

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