Session Number 3.5: Biodiversity

ELEVATED ENCLAVES – LIVING ROOF BIODIVERSITY ENHANCEMENT THROUGH PROSTHETIC HABITATS

Renee Davies, Robyn Simcock, Graham Ussher, Cris deGroot, Martin Boult, Richard Toft

Unitec Institute of Technology/Landcare Research Ltd/Tonkin & Taylor Ltd

Abstract

Living roofs offer an opportunity to bring conservation into a contemporary context integrated within urban landscapes. Once neglected and under-utilized roof landscapes can now become biodiverse enclaves of indigenous flora and fauna.

The microhabitat variables required for lizards, including temperature, humidity, refuge/shelter and prey, on New Zealand's first fully indigenous (a plant or animal which occurs naturally in NZ) (Department of Conservation 2000) (4) extensive living roof were studied over three years. Temperature and humidity data from a known lizard site was used to assess the suitability of the living roof in conjunction with a comparison of insects monitored on the living roof and a literature review of lizard diet. This data provided a team of ecologists, landscape architects and product designers with the parameters needed to develop, prototype and field-test a prosthetic habitat that provides enhanced conditions on the living roof for lizards.

Results indicate a New Zealand indigenous extensive living roof plant community can provide the basic microhabitat variables required to support lizards with the exception of humidity. Although existing vegetation will provide refuge from predators and modifies temperature and humidity, the designed prosthetic habitat creates humid micro-sites (refuges), allowing a trial translocation of native skinks.

Introduction

Living roofs have been identified as enhancing urban biodiversity compared to conventional roofs, particularly biodiversity associated with ruderal habitats (Brenneisen 2007; Jones 2002) (2, 10). Extensive (<150 mm deep) living roofs are particularly valuable as habitat as they generally have low levels of disturbance associated with maintenance and are not designed to support people. However, research to date has focused on enhancing natural, ad-hoc plant, insect and bird colonization of living roofs, primarily by spontaneous colonization of natural soils or rubble, addition of wood and creating vegetation-free sites (for nesting birds) (Lundholm et al, 2008, Oberndorfer, et al 2007) (11, 17). Specific opportunities for relocation of endangered species have been demonstrated for bird, notably the redstart in London. Prior to this research programme there was no research within the New Zealand (NZ) context on biodiversity opportunity on living roof systems.

Living roofs are potentially ideal sites to establish native NZ skink (*Oligosoma sp.*) populations in the NZ context as they are infrequently accessed by people (extensive living roofs in particular), represent new habitat so can be made free of mammalian predators (non-native mice, rats, hedgehogs and cats) and the non native rainbow skink (*Lampropholis delicate*), which may compete with native *Oligosoma* species (Peace, 2004) (19). We proposed that living roofs could be manipulated to provide habitat and climatic conditions suitable for NZ indigenous skinks.

Since 2004, local regulatory authorities have required rescue, relocation and habitat restoration of urban NZ indigenous lizards (skinks and geckos) where they are impacted by small developments such as buildings and roads. To date, there is no evidence that relocation of skinks to other locations assists the relocated skinks or how the resident skinks that are inevitably present are impacted. Living roofs potentially provides new habitat with known environmental conditions into which skinks could be relocated. Monitoring skinks on roofs is easier than on the ground as skinks can be relatively easily retained on a roof with adequate vegetation cover, vegetation free edge (skinks prefer to stay close to vegetation) and suitable parapet or flashing (skinks are not good climbers, having claws not sticky pads (G Ussher 2010 pers. Comm., 30 September). The WCC living roof is surrounded by a 40cm high aluminum covered parapet. Skinks are unlikely to climb over this parapet edge.

Skink Habitat Requirements

The general habitat requirements were reviewed to assess the potential for extensive living roofs to support skinks. Requirements include refuge from predators, food and suitable thermal conditions (Howard, Williamson & Mather 2003) (9). Protection from predation is inferred by degree of isolation or exposure such as canopy cover, and aspects of ground cover such as presence of grasses, structure of the litter layer, or amount of woody debris or rocks (Howard, Williamson & Mather 2003) (9).

Key findings from a study of four species of skink by Stephens (Tocher 2003) (23) indicated that there are positive correlations between the density of skinks, their food sources, and the temperature of the environment, and a negative correlation with the presence of predators, highlighting the need for all these habitat requirements to be met.

All these variables are likely to influence an individuals' ability to thermoregulate, feed and avoid predators (Howard, Williamson & Mather 2003) (9) and become the key habitat requirements to be assessed on the living roof in order to determine if the living roof will provide the core requirements for establishment of viable skink population/s.

Temperature and Humidity

Whitaker (1997) (27) outlines that skinks regulate their body temperature through the environment (they are ectothermic). Skinks can be either thigmothermic (rarely bask and obtain heat from warm substrates), or heliotherms (that bask in open areas and on the surface of vegetation). This physiology means that temperature is one of the important factors in the ecology of skinks (Muchna 2009) (14). Thermal conditions influence habitat choice because of their strong effect on short-term physiological performance (Pounds & Huey in Howard et al 2003) (9). Skinks are more thermally efficient if their environment provides sites to which they can move to either raise temperature to optimum levels, or avoid overheating (Howard et al 2003) (9).

Access to adequate heat sources enables the survival and reproduction of skinks. Behavioural activities such as basking, burrowing, selection of warm refuge sites and aggregating are some of the ways skinks adapt to temperature variables (Muchna 2009) (14). This study by Muchna (2009) (14) highlighted microhabitat preference was linked with improved thermoregulatory opportunities. Boulder habitats have been shown to provide thermal stability for reptiles (Neilson & Keri 2002) (16). Skinks drink water, swim well and will deliberately sport in water (McCann 1956) (13), and humidity is an important factor in determining habitat use by skinks (Neilson & Keri 2002 and Cree & Daugherty 1991) (16,3). The key function of the prosthetic habitat was to assist with thermoregulation (see refuge methodology) by providing both humid, cool refugia and warm basking surfaces.

<u>Diet</u>

Most research on lizard diets has emphasized the largely opportunistic nature of lizard foraging: most lizards are generalists (Freeman 1994) (5), although preferences tend to vary from species to species.

Studies on skink prey have noted the small size of prey items taken by NZ skinks in relation to their size (Ussher 2005 & Patterson 1985) (28, 18), however, larger skinks consume larger prey (Montoya & & Burns 2007) (15). Some skinks are known to be frugivorous, including plant material, in particular, fleshy fruits, in their diet (Ussher 2005) (28).

Availability of prey species and if possible, appropriate fruit and nectar, is a key component of determining the viability of the living roof as a skink habitat. At any given site the abundance and diversity of invertebrates and fruit are influenced by the composition of the local vegetation (Toft et al 2003) (24). As such the vegetative composition and relative vegetation cover of the living roof becomes an important factor in the number of prey organisms.

Project objectives are to identify the specific habitat requirements of NZ skink species and confirm whether these conditions exist and/or can be created (using prosthetic habitats) on a living roof. The project also seeks to quantify the insect population and vegetation cover provided by an existing 500 square meter NZ indigenous living roof to ensure it can sustain a population of skinks.

The key research questions posed are

- Can living roofs increase NZ flora and fauna diversity in urban environments?
- Can habitats suitable for supporting biodiversity be provided while improving and maintaining aesthetic roof landscapes?
- Can a NZ living roof provide habitat conditions suitable for relocation of NZ lizard species?

- Can prosthetic lizard habitats provide habitat and refuges for NZ lizard species, both on roofs and on the ground?

This paper provides detail on the first stage of the research project. Results to date provide preliminary answers to three of the research questions and allow an application for authority to trial relocation of skinks to the living roof.

Study Areas

Two monitored sites support the research; an extensive living roof and a protected site with known skink populations.

Waitakere City Council Extensive Living Roof

The Waitakere City Council's extensive living roof was planted in the winter of 2006 and tops a 3-storey building on Henderson Valley Road in Auckland City. The 500 square meter living pioneered the use of an extensive system featuring indigenous NZ plants, and remains New Zealand's largest extensive living roof. Council's vision for the living roof was to demonstrate the range of sustainable benefits of living (green) roof technology, to create a living roof specific to the New Zealand situation, and at least in part, to reflect the plant species found in the Waitakere environment. This was achieved via a documented process for plant and substrate selection and performance with respect to storm water, habitat and amenity.

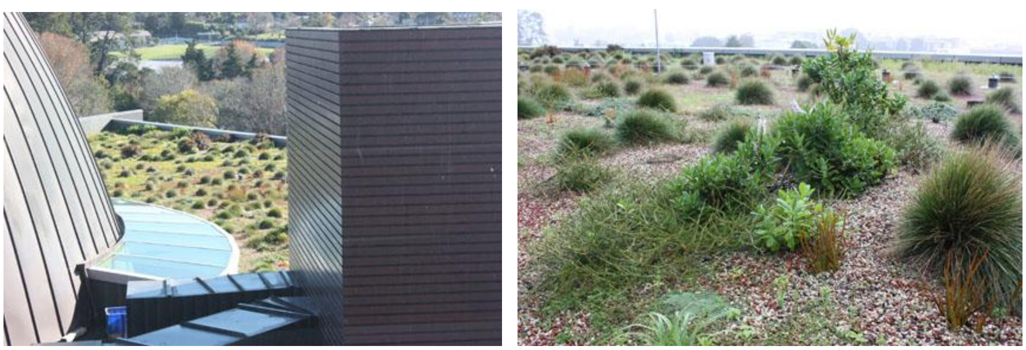

Figure 1a and 1b: The Waitakere Civic Centre living roof in June 2010 (mid winter) viewed from the adjacent building and showing the diversity of plant growth forms from tussocks (*Festuca coxii*) and spikey orange irises (*Libertia peregrinans*) to tangled ground covers (*Coprosma acerosa*) and dense mounds of NZ hebe (*Hebe obtusata*).

Indigenous NZ plants which have been successful on the roof in at least 100mm of substrate and with supplemental summer irrigation include; *Astelia banksii, Coprosma acerosa, Dichondra repens, Festuca coxii, Haloragis erecta, Haloragis erecta* 'Wellington bronze'*, Hebe obtusata, Hebe pimeleoides* subsp*. Fauicola, Leptostigma setulosa, Libertia peregrinans, Muehlenbeckia complexa, Pimelea prostrate, Pimelea* aff. *urvilleana, Plantago triandra, Raoulia hookerii, Raoulia parkii, Selliera radicans and Scandia rosifolia*. In the absence of irrigation only *Festuca coxii*, *Coprosma acerosa*, *Dichondra repens* and *Libertia peregrinans* were largely successful.

Shakespear Regional Park, Pistol Paddock

Shakespear Regional Park is located on the Whangaparaoa Peninsula in Auckland. The park is approximately 375 ha in size and is managed by the Auckland Regional Council as both a working farm and a recreational park. The park contains two mammal-free grasslands which are known to have indigenous skinks, including the copper skink (*Oligosoma aeneum*), endangered moko (*Oligosoma moko*) and ornate skinks (*Oligosoma ornatum*) (Van Winkel 2009) (29). A lizard protection plan aims to protect and improve the skinks populations (Ussher 2005) (28). The primary research site is a 1 ha area called Pistol paddock. The dominant vegetation is exotic grasses (including but not limited to; *Holcus lanatus, Lolium perenne*, *Pennisetum clandestinum*, *Poaceae* spp. and *Rumex obtusifolius*). Native sedges (*Carex* spp.), flax (*Phormium tenax*) and toe toe (*Cortaderia fulvida*) create tussocky clumps up to 0.5m to 1.5m high interspersed with native groundcovers, including *Coprosma* spp. and *Muehlenbeckia complexa*. This vegetation mix is a naturally occurring mix which most closely resembles the structure of the vegetation that the WCC living roof may eventually support, being tussocky clumps within dense, low herbaceous cover.

Materials and Methods

The methodology for the first stage of this research project focuses on data collection related to the three key variables that influence the suitability of the environment for lizards: temperature/humidity (thermal conditions), diet (food and prey) and refuge (shelter). The methodological approach and subsequent results to date for each is outlined under these key headings.

<u>Primary study species</u>

The focus of this research is on the conservation management potential of living roofs for NZ indigenous skinks (Genus *Oligosma*; Chapple et al. 2009) all of which are endemic to the NZ Region. Many NZ skinks are rare or threatened species (Towns1999) (25) and creation of new populations would assist with recovery efforts. Most (if not all) skinks species are sensitive to predation by mammals (Towns & Elliott 1996) (26), hence the potential for living roofs to be mammal-free lends itself to possible conservation efforts in relation to skinks.

For the purposes of the preliminary phases of the project, the copper skink (*Oligosoma aeneum*) has been identified as the primary species for research as they are known to use a wide range of habitats including long grass, compost heaps, urban gardens, native forest, open rocky sites and coastal habitats (Peace 2004) (19). Despite its protected status it is not cuurently considered rare or threatened and permits for relocation are more likely to be obtained. Copper skinks are NZ's smallest native lizard, are viviparous (live bearing), as are all but one of the native lizards, and crepuscular or diurnal (Peace 2004) (19).

<u>Temperature and Humidity</u>

Daily and seasonal maxima and minima temperature (degrees Celsius) and humidity (%) data are being gathered via multiple temperature and combined temperature and humidity data loggers located at different locations on the Living roof and Shakespear. Areas of open ground, dense vegetative cover and sparse vegetative cover are monitored, along with the prosthetic habitats. Readings are taken every ten minutes for fourteen consecutive days at which time the data are downloaded. This information is used to compare skink habitats at a terrestrial site (Shakespear) and the living roof. Data will be collected for a full year, covering all seasons. To date, late autumn, winter and spring data have been collected.

Comparison of data aims to provide relative benefit of presence, absence and types of vegetation and whether there is a gap in presumed habitat quality between natural and living roof sites. The data will also identify the most suitable plant species that best match refuge conditions by comparing microclimate conditions of particular plant structure on the living roof with conditions at the Shakespear site.

Diet

Prey availability was assessed on the WCC living roof by classifying invertebrate fauna over a two year period. In addition, a literature search of existing dietary data for indigenous and introduced skink species was undertaken and this formed the basis of a preliminary gap analysis of food potential on the living roof. Due to lack of research data on NZ skinks, information on diet and behavior of all NZ skinks has been analyzed to inform the research.

The WCC living roof was assessed in the first and second summers during development of plant cover in the absence of irrigation. Severe drought in the second summer meant a relatively stable plant cover and leaf humus layers, both important invertebrate habitat, were not achieved in this timeframe. Parts of the roof were replanted and an irrigation system installed 2009 and 2010 to increase the plant cover and density. The abundance and diversity of native and exotic invertebrates are being re-measured in summer 2010 to provide additional assurance prior to any proposed skink relocation. The invertebrate monitoring methods on the living roof include the following:

Wooden refugia - untreated radiata pine discs (c. 250 mm diameter and 40 mm depth), with bark removed, placed on the living roof (10 in total with 1 placed every 50 square meters). The discs act as shelters or refugia and habitat for invertebrates. Discs are lifted quarterly and the resident invertebrates counted, photographed and, where possible, identified.

Emergence trapping - these 48 x 48 cm traps (c. 0.23 m^2) catch insects that emerge from the enclosed vegetation or substrate. This provides an absolute measure of insects per unit area, and the entirely enclosed nature of the trap ensures the invertebrates collected were truly resident on the living roof.

Pitfall traps - pitfalls are the most common method used to monitor invertebrates in living roof studies in Europe. Pitfalls were deployed for 4 weeks in summer, when insects are most active, and were emptied every 7 days. Approximately 1 pitfall per 20 m^2 of living roof (a total of 10) and 2 pitfalls on the adjacent conventional roof were deployed.

The literature of skin food used faecal pellets from skinks collected and the scat material examined for food remains and gastrointestinal contents analysis undertaken from dead skink specimens.

Refuge/Habitat

Vegetation cover and species growth and success has been monitored on the living roof since its initial implementation in 2006 and continues using three techniques. (1) - Permanent circular vegetation plots (10 in total) in a zone along the centre of the living roof. Plant species in each plot, and x,y dimensions of the *Coprosma acerosa* was noted. (2) - Ten 1m x 1m randomly placed grids with 81 intercept points (and noting what was under each spot) and (3) - photo points.

Given the microclimate requirements of skink, in particular refuge and thermal regulation we decided an artificial or enhanced habitat and refuge opportunity was likely to be important to ensure adequate humidity and cool temperatures in summer, and warm basking surfaces in winter.
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Traditional habitat enhancement for skinks in New Zealand has focused on the use of layered corrugated onduline or iron sheeting and piles of logs. Neither are ideal for the living roof scenario. Logs can be heavy and are difficult to disassemble (for monitoring purposes), and corrugated iron could be lifted by wind, has sub-optimal thermal and humidity characteristics and would be difficult to anchor to shallow living roof substrate. The artificial habitat refuge is being developed as a potential substitute for the typical refuges and habitats that would otherwise be afforded by the features within a natural environment. Such an artificial substitute is being conceptually termed by the researchers as a prosthetic habitat due to its designed functionality.

A design team of undergraduate Product Design students were briefed by the research team on the range of habitat requirements of skinks and the particular extreme conditions encountered on living roofs. This formed the ‘client brief’ used to develop early prototypes. The range of environmental factors necessary included shelter, refuge, food, territory, water, humidity warmth, aesthetics and monitoring.

Results

Temperature and humidity

Temperature and humidity data has been collected for six months, covering the autumn to early summer. The living roof experiences more extremes in temperature than the Shakespear site, in particular higher midday temperatures but also lower night temperatures. Maximum daytime temperatures are considerably lower in locations on the living roof where there is shelter and shading from vegetation (data logger no 2 in figure 2, located amidst grouping of *Festuca coxii,* no 1 being open location and no. 3 being open location on living roof) and that *Festuca coxii* on the living roof provides a comparable temperature as the vegetated cover sites at Shakespear (no. 4 with no cover, no. 5 being located under shade of a large log, no. 6 being located under *Phormium cookianum* and no. 7 being located under perennial grass and in the open).

The importance of vegetation cover in moderating temperature extremes on the living roof to closer achieve thermal properties equivalent to those that might be found in ground sites for skinks has been shown by the results. The native tussock-forming species *Festuca coxii* and *Astelia banksii* appears to be particularly important in creating cooler micro-sites as shown in figures 2 and 3.

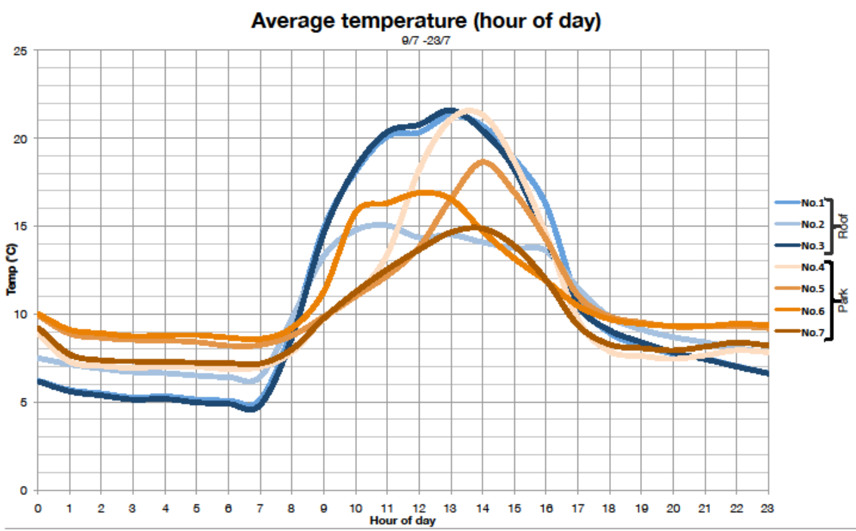


Figure 2: Comparison of average temperatures for loggers over one fortnight located at WCC living roof and Shakespear Regional Park

Figure 3: *Festuca coxii* (data no. 2) creating microhabitat which reduces temperature extremes on WCC living roof

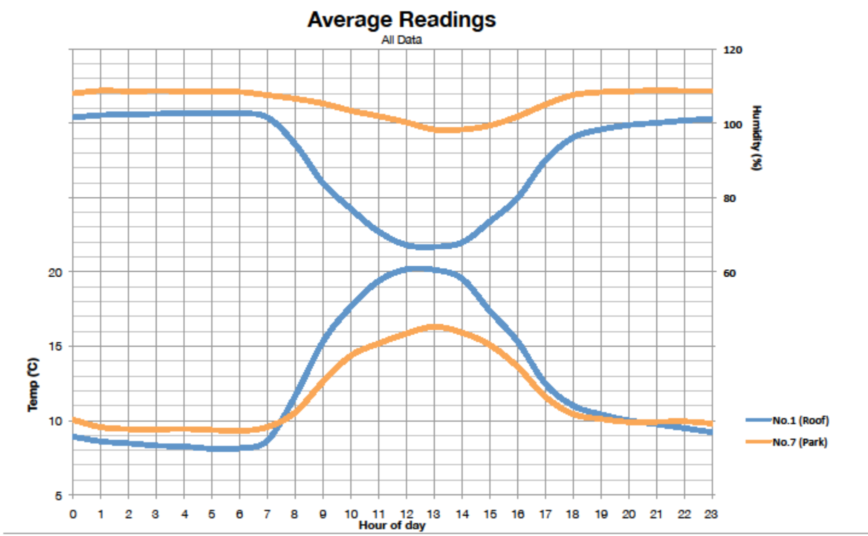


Figure 4: Comparison of average of all data for humidity (top) and temperature (bottom) for data stations 1 and 7 at WCC living roof and Shakespear regional park

Humidity level s are lower, particularly during the middle of the day and are more extreme on the living roof compared to the Shakespear park site (Figure 4). This emphasises the importance of providing prosthetic habitats on the living roof as these contain water reservoirs.

Diet

Insect monitoring over three years has confirmed a range of invertebrate herbivores, predators, detritivores, and parasites are present on the roof. The self introduced invertebrate community on the living roof to date is strongly biased towards adventive species and a few ubiquitous native species that together are typical of degraded anthropogenic habitats in New Zealand, (Spencer et al 1998) (21).

Results of the resource gap analysis (Table 1) show the funcitional taxa currently present on the living roof and that may be part of the natural diet of skinks. The range of food types generally matches (16 out of 26) known diets of NZ skinks. Of these, all but 3 of the top 5 recorded insect orders noted in skink diets across the range of skink species have been recorded on the living roof. Of the 6 gaps in invertebrate orders on the living roof, the key gap is the order isopoda (slaters).

The range of habitats and availability of invertebrates on living roofs has been increased using wood refugia and insects (in particular arthropoda) have colonised the prosthetic habitat at Shakespear. Seeding of insects from the missing orders onto the living roof is therefore considered possible and recommended despite the opportunistic and generalist nature of lizards, indicating skinks on the living roof will prey on whatever species are present. Augmentation will however increase the range of food availability and choice.

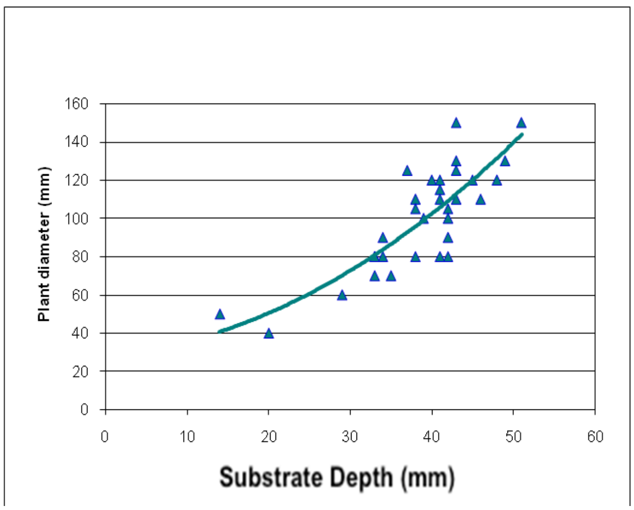
Both *Coprosma acerosa* and *Muehlenbeckia complexa,* two plant species surviving on the living roof have fleshy fruits from Genera which have been documented to be included in the diet of some skinks (*including O. aeneum*) as outlined in the food organism records outlined in Table 1. Both species have produced fruit in small volumes to date; supplemental irrigation is anticipated to increase the cover (hence fruit volume) of both these species.

Skink Species or Location *Nomenclature for skinks follows current taxonomy provided by Chapple et al. 2009.*	**Food Organism Type** *Shaded area: Noted in food organism analysis* *1 – 5: top 5 food organisms – 1 being most common* ** Not collected with current methodologies* *Australian species only – recorded from Australian research site for Rainbow skink* *Phyllum or Ordinal rank used for identification* *n/a – living roof environment does not support habitat for these orders*																										
	Orthoptera (grasshoppers, crickets)	*Hemiptera (true bugs)*	*Coleoptera (beetles)*	*Lepidoptera (butterflies, moths)*	*Diptera (flies)*	*Hymenoptera (ants, wasps, bees)*	*Thysanoptera (thrips)*	*Dermaptera (earwigs)*	*Amphipoda (sand hoppers)*	*Isopoda (slaters)*	*Araneae (spiders)*	*Acarina (mites)*	*Collembola (springtails)*	*Mollusca or Pulmonata (slugs & snails)*	*Nematoda (roundworms)*	*Plant material*	*Opiliones (harvestmen)*	*Chilopoda (centipedes)*	*Psocoptera (booklice)*	*Pseudoscorpionidae (false scorpions)*	*Oligochaeta (earth worms)*	*Diplopoda (millipedes)*	*Odonata (dragonflies, damselflies)*	*Platyhelminthes*	*Neuroptera (lacewings)*	*Isoptera (termintes) from Australian sites*	*Other*
Oligosoma aeneum (1)		1			5	4				2		3															
Oligosoma aeneum (18)			2			5					3	1				4											
Oligosoma zelandica (1)		3	5		2					4					1												
Oligosoma zelandica (7)					5	4					1						3										2
Oligosoma sp. (7)		5		4							3		1				2										
Oligosoma grande (22)			4		1	3										2											5
Oligosoma polychrome (20)	4		1	2							3										5						
Oligosoma polychrome (5)																											
Oligosoma maccannii (16)		2	4	5	3						1																
Oligosoma maccannii (5)																											
Oligosoma lineoocellatum(20)			2	5		3															1	4					
Oligosoma otagense (22)	5		2		3	4										1											
Oligosoma ornatum (18)			1			5						3		2		4											
Lampropholis delicate (11)		2			3						5		4													1	
WCC Living Roof 2007																											
WCC Living Roof 2008																											
Gaps in Food Organisms on Living Roof															*								n/a	n/a	n/a	n/a	

Table 1: Summary of recorded food items and top 5 food items (if known) for New Zealand skink

Refuge

Native plant cover and diversity over the first three years peaked in Spring 2007 (64%, all planted species present), however dropped to around 30% cover in early winter 2008 (3 years after planting) following a protracted drought. Vegetation cover then improved after irrigation was installed on the living roof and has now recovered to c70% native cover on these areas (Figure 9). Substrate depth over this time varied from 40 to 150 mm depth. The tussock *Festuca coxii* provided most of the native plant cover at substrate depths less than about 80 mm depth. There was a relatively strong link between diameter (health) of planted *Festuca coxii* at age 3 and substrate depth and native plant species numbers on the WCC living roof. The value of *Festuca* for lizards lies in its dense growth form that modifies temperatures (Figure 2) and supports invertebrates that feed in the matted skirt of dead leaves and its impact on reducing temperatures on the living roof.



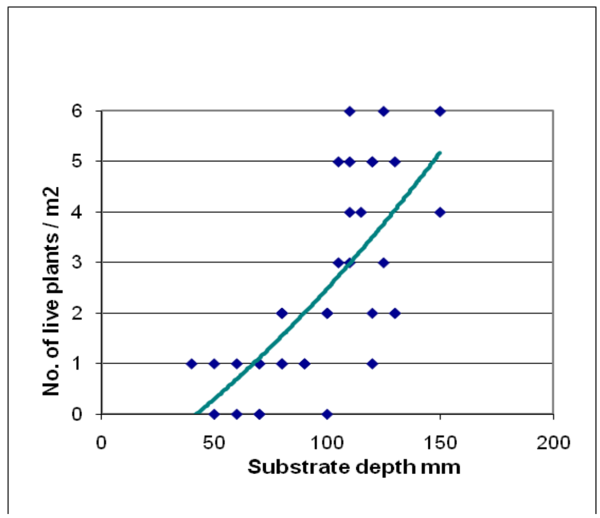


Figure 8: Relationship between substrate depth and diameter of *Festuca coxii* (left graph) and live native plants per m² (right graph) at age 3, before soil amendment and irrigation.

The growth of creeping groundcover species <30 mm tall, e.g., *Leptostigma setulosa, Dichondra repens* and *Selliera radicans* was visibly denser and taller in the shade provided by larger (100 to 300 mm tall) plants such as *Coprosma acerosa*, *Festuca coxii* and *Libertia peregrinans*, demonstrating the value of combining species that have contrasting growth forms.

Irrigation and the supplementation of substrate depth to a minimum 100 mm depth has allowed the establishment and increased survival and diversity of flowering and fruiting native plant species (such as *Hebe obtusata*) that may attract insects or provide supplemental food for lizards and taller herbs such as *Haloragis erecta*.

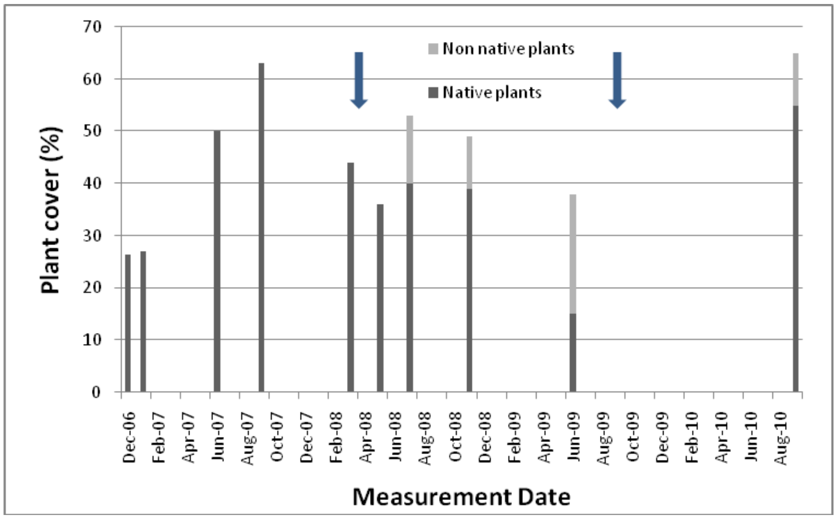
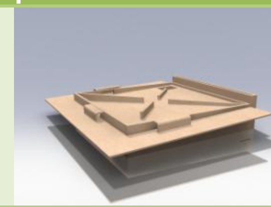
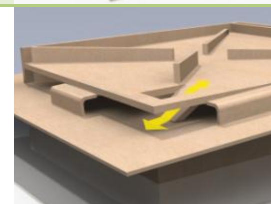
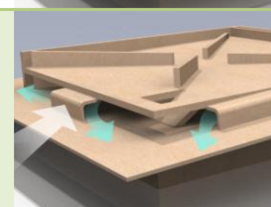
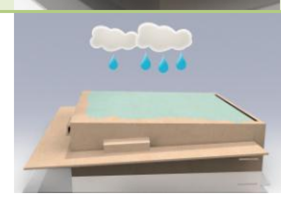
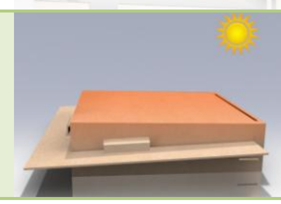


Fig 9: Vegetation Cover from December 2006 to June 2009 (when the roof was renovated) and September 2010 (post renovation). Arrows indicate when intensive invertebrate trapping was started. Data based on permanent circular plots shows total plant cover was similar in both invertebrate trapping periods, being 63%±11 (September 2007) vs. 49%±19 (Nov 2008), however, there was more dead native plant material on the roof in December 2008. This includes about 30% of planted *Coprosma acerosa*, most *Muehlenbeckia complexa* and overall more than 20% of native vegetation. In November 2010 native cover on established irrigated areas was c. 70%; cover on newly irrigated areas was 30% and expected to rapidly increase.

It should be noted that the non natives present on the living roof (Figure 9) are self seeded colonizers. There is no evidence to suggest that these non native species are providing lower quality habitat. Some are non-invasive and as such contribute to the overall diversity of the living roof and are not being targeted for removal through the quarterly weeding of the living roof.

The prosthetic habitat that has been developed, provides both functional substitutes for primary habitat requirements (in particular refuge and thermal regulation) for skinks while also being aesthetically appropriate for the living roof environment and functionally suitable for the particular conditions the prosthetic habitat would be subject to on the living roof.

The most suitable concept that emerged from the early design phase developed the premise of establishing a layered approach to the habitat, enabling a variety of distinct environment conditions to be available to the skinks for self-regulation of temperature and humidity. Furthermore, this basic concept can potentially support the persistence of suitable environmental conditions throughout the year in otherwise inhospitable contexts. Specific design responses in relation to the criteria mentioned above are summarized in the following table.

Consideration	Known Habitat Requirements	Design Response	Illustration of integration into prosthetic habitat
Refuge	Crevices 4 – 12mm in height (based on copper skink size)	Interior spaces are graduated to provide a range of depths for wedging opportunities for different sizes of skink (young to adult)	
Territory	Group and Individual areas	Partitions within layers to increase territory opportunity thus increasing numbers able to be accommodated Ramps provide access between layers and increase areas for habitation	
Shelter	Shade from extreme heat Protection from rain Protection from wind	Roof provides shade and subsequent layers trap cooler air. Rain protection via roof and overlapping wall design Entrances are aligned to reduce impact from wind	
Water	Access to potable water Maintenance of humidity	Water collected on sloped roof and directed toward water reservoir in bottom level , accessible to skinks for drinking and bathing via ramp Water reservoir provides resource for establishing variable degrees of humidity across the separate layers. Hygroscopic construction material further supports humidity maintenance during dry periods.	 
Warmth	Basking opportunity Ability to move between variable temperatures	Roof provides large basking area and top roof layer can be coloured to increase thermal properties (e.g. dark colour) Materials chosen for high thermal mass, to act as heat sink	
Monitoring	Need to be able to assess if skinks are using artificial habitat by viewing inside the layers Need to access temperature and humidity monitoring equipment on each layer	Small and transportable Layers easily removed and re-assembled to enable monitoring of skinks Entrance 'verandah' provides opportunity for monitoring of lizard activity with ink tracking pads Entrances can be closed off easily to capture skinks in artificial habitat for monitoring	

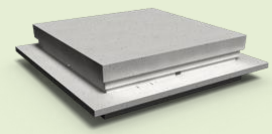
Aesthetics	Needs to have an aesthetic appeal on living roof Needs to be anchored onto windy roof environment	Material can be coloured as required to either blend in or contrast with living roof environment/vegetation Bottom layers are located below ground level, thus securing to living roof Layers lock together to prevent movement in windy conditions	

Table 2: Prosthetic habitat design considerations and responses

The prosthetic habitat has been molded from a durable ceramic that can withstand weather conditions typical for the region. Monitoring of installed prosthetic habitats (Figure 10 a and b) is underway.

Skinks were using two of the three prosthetic habitats at Shakespear after two weeks. In pads (to record animal footprints) have been placed in the entrances of each habitat to help quantify the extent of use.

Figure 10a and 10b: Photograph of completed prosthetic habitat at both study sites, Shakespear Regional Park on left and WCC living roof on right.

Discussion and Conclusions

This paper outlines the first stage results of environmental monitoring associated with assessing the potential of a living roof for skink habitation and outlines the collaborative process undertaken to develop a prosthetic habitat which enhances this potential, particularly given the lower humidity levels on the living roof compared with ground sites.

Micro-climate data indicates temperatures under dense vegetation on the living roof in the late autumn, winter and spring seasons are similar to vegetated ground sites at the known lizard habitat of Shakespear. Temperature and humidity data will continue to be collected from the living roof, prosthetic habitats and field sites over summer to indicate skinks are likely to be able to survive on the ‘enhanced’ WCC living roof. The main requirement currently lacking a the living roof is high humidity. Addition of the prosthetic habitats should create humid microhabitats.

The living roof currently provides a range of prey species for skink. Seeding of some native insect species such as orthoptera and isopoda and a proactive approach to management and addition of materials to continually increase invertebrate abundance and/or diversity can be undertaken to further increase the level of suitability of the living roof.

Prosthetic habitats are required as substrates on roofs are shallow, lightweight and dry out rapidly. The prosthetic habitat prototype has shown that environmental requirements for a particular species can be met through the design of a specific habitat which responds to species needs alongside the logistical and aesthetic requirements of the living roof situation – confirming that a NZ living roof can provide (with augmentation) suitable habitats while maintaining an aesthetically appropriate roof landscape. The confirmed use of the prosthetic habitat by skinks in the field soon after installation shows their potential success as habitat on the ground. Stage 2 of the research (an actual relocation of skinks to the living roof) will be required to confirm if the living roof prosthetic habitat plays the same role.

If summer 2010/11 monitoring confirms interim results to and prosthetic habitats increase humidity levels on the living roof, the second stage of the project (the introduction of a NZ skink to the living roof) will proceed. The introduction of skinks to the living roof will confirm if the living roof, with prosthetic habitat can play a role in increasing NZ faunal biodiversity in an urban environment. The lack of knowledge linking copper skink population abundance with invertebrate food abundance means any introduction will be stepwise, using an adaptive management framework. Skinks will be introduced at low densities and their health monitored before attempting to establish numbers required for self-sustaining population.

Acknowledgements
The authors thank Unitec Product Design students Nick Gill, Melody Duan and Aaron Hop, Unitec landscape technician Trina Smith, Waitakere City Council, especially. Danielle Hancock , Auckland Regional Council, in particular Matt Maitland (Open sanctuary co-ordinator) and Dave Craddock (herpetologist) and Landcare Research colleagues Chris Winks and Darren Ward (invertebrate collectors), Jo Rees and John Dugdale (invertebrate taxonomy) and Colin Meurk (plant identifications).

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