Landscape for Life - An investigation of opportunities for aesthetic improvement and biodiversity enhancement for living roofs in New Zealand

Renee Davies

Executive Summary
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 extensive living roof have been studied over three years. Temperature and humidity data from a known lizard site has been 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 has provided the research team (an interdisciplinary 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 from stage 1 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.

The results of stage 1 have are now providing a solid basis for stage 2 of the research which has met with Department of Conservation approval in principle (meeting held in February), for the progression to a permit for a trial relocation of skinks onto the living roof.

Project highlights:
- Working with product design researchers and students to brainstorm the prosthetic habitat concept.
- Feedback from International conference which confirmed some of our preliminary results on living roof environmental conditions and emphasised the International relevance of the research.
- A field visit to Shakespear Regional Park where the prosthetic habitats were put into the field and seeing evidence of lizard use of the habitats.

Background
Living roofs have been identified as providing significant potential for urban biodiversity within a range of living roof literature including English Nature.

However, research to date has focused on natural and ad-hoc plant, insect and bird colonisation of living roofs as opposed to specific opportunities for relocation of endangered species. There has been no research within the New Zealand context on biodiversity opportunity (other than that initiated at the Waitakere City Council living roof – project managed by myself in collaboration with Landcare Research). The initial results from this research indicated that this NZ native living roof provides a significant insect diversity which might sustain lizard populations. Internationally, there is a limited resource of habitat

biodiversity research on living roofs (particularly those with native plant species (compared with the more common sedum roofs).

Since 2004, Rodney, Waitakere, ARC and other councils have applied consent conditions regarding rescue, relocation and habitat restoration for urban lizards on small developments (down to single-lot size). This generates many lizards that need to be put somewhere. However, there is no evidence that relocation of skinks to other locations assists either the relocated skinks or the resident lizards that are inevitably present.

Living roofs are potential ideal sites to establish populations of skinks: they are not walked on by people, represent new habitat, are unlikely to have the pest mammal issues that the more 'terrestrial' habitats have, free of the introduced rainbow skink, and can be designed to provide climatic conditions suitable for lizards and should be capable of supporting viable lizard populations. Living roofs can therefore be permanent reservoirs for less common local species and have the particular advantage of keeping lizards within iwi boundaries – retaining local taonga in local places.

This research (1st stage) aimed to provide preliminary quantifiable data on whether an existing New Zealand native living roof has the required insect and plant structure and diversity to support a lizard population. It also investigated ways to optimise the habitat and refuge potential of the living roof through the use of a designed habitat objects.

Aims and Objectives

In terms of the original ambitions for the project, stage 1 of Landscapes for Life has achieved the following in terms of aims and objectives:

- Identify the specific habitat requirements of New Zealand lizard species and confirm whether these conditions exist or can be created (using prosthetic habitats) on living roofs. **(mostly completed in stage 1, still awaiting final later summer, early autumn data)**
- Quantify the insect population and vegetation cover that is provided by an existing 500square metre living roof (Waitakere City Council building). **(completed in stage 1)**
- Develop a range of prototype habitat objects which may assist the creation of optimal habitats for New Zealand lizard species on living roofs. **(completed in stage 1)**

Stage 2 looks to add to the above by the following:

- Augment existing invertebrate communities on the living roof by releasing NZ native slaters and crickets onto the roof. **(Stage 2)**
- Obtain a permit to undertake the relocation and subsequent monitoring of a small population of copper skinks onto the living roof. **(Stage 2)**
- Continue to quantify the insect population and vegetation cover that is provided by an existing 500square metre living roof. (**Stage 2 – year 4 assessment)**

Lead to Stage 3 of research which will involve continued monitoring of skink population on living roof and assessment of potential population capacity of living roof. Investigation of potential urban habitat opportunities for living roof in Auckland and beyond and investigation of terrestrial conservation potential of prosthetic habitats.

The aims and objectives outlined above have not changed through stage 1 of the project.

Methodology

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.

Primary study species

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).

Temperature and Humidity

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.

.

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.

Outcomes/findings

In terms of the research questions as outlined below, the stage 1 research has answered questions 2, 3 and 4 and stage 2 of the project will further quantify these results and assist in answering the question 1. Details of the results to date are outlined in this section, with additional graphical information and data provided in Appendix 1. Full statistical analysis if pending the final data collection from late summer, early autumn.

1. Can living roofs provide for increased New Zealand flora and fauna biodiversity in urban environments?
2. Can optimal habitats be provided while improving and maintaining aesthetic roof landscapes?
3. Can a NZ native living roof provide habitat conditions suitable for relocation of NZ native lizard species?
4. Can built habitat objects located on living roofs contribute to optimal habitat and refuges for New Zealand lizard species and their associated insect food sources?

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.

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. 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 show the functional 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. 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.

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. 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 and supports invertebrates that feed in the matted skirt of dead leaves and its impact on reducing temperatures on the living roof.

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*.

It should be noted that the non natives present on the living roof 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.

The prosthetic habitat has been molded from a durable ceramic that can withstand weather conditions typical for the region. Monitoring of installed prosthetic habitats is ongoing.

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

Key achievements for 2010:

- Auckland University Ethics Committee approval gained on 9th April 2010.
- ARC Permit for field study at Shakespear Regional Park approved on June 10th 2010.
- Establishment of field sites at Shakespear Regional Park with Graham Ussher and lizard researcher from ARC in June 2010.
- Humidity and temperature logger information working and providing interesting data and comparisons between Shakespear and green roof an within different environments on the green roof.
- Discussion on the potential of the habitat objects with herpetological experts – they are very interested and this could have interesting applications for broader skink conservation efforts depending on outcomes of field testing of the prototypes.
- Completion of habitat design by product design students – excellent result with real viability for application in field.
- Abstract accepted for Cities Alive Conference, Vancouver November 2010 (part of FCIB research funding for Renee Davies). Will produce refereed outputs and provide key contacts and information which will be of ongoing use for this project.
- Completion of a minimum of 5 prototype habitats for testing in field.
- Additional planting being undertaken on WCC green roof to augment existing planting. This will support project outcomes.
- Ongoing temperature/humidity monitoring (including inside artificial habitats) fortnightly.
- Insect monitoring in November/December 2010.
- Establishment of preliminary view on viability of lizard habitat on green roof – to determine likely components of stage 2.

Conclusions

The first stage results of environmental monitoring associated with assessing the potential of a living roof for skink habitation and development of a prosthetic habitat which enhances this potential, particularly given the lower humidity levels on the living roof compared with ground sites have provided enough positive data to proceed with stage 2 of the research.

Micro-climate data indicates temperatures under dense vegetation on the living roof in the late autumn, winter, spring and summer 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 late summer and autumn 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 and data to date indicates this.

The living roof currently provides a range of prey species for skink. Seeding of some native insect species such as 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.

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.

Implications

Indicate who will benefit from the research, how, and why. Consider the future implications of your work and how others can build on it. What are the implications for other stakeholders, for users, or for the community? What work could be undertaken to build on your research or carry it further?

The potential of living roofs to contribute to biodiversity in urban environments is a current topic of interest worldwide. However, the discussion is not supported by much research and none in New Zealand (beyond the existing WCC work).

Currently, there has been no deliberate lizard relocations onto living roofs in New Zealand (and as preliminary literature reviews would suggest), neither has this occurred internationally. This potential however, has been discussed. This research will address this gap in information within a specifically New Zealand context and as such, the results of this project will be of interest to living roof researchers, conservation biologists and local authorities and developers involved in projects which impact on lizard populations.

The results of the habitat object trial will be of interest to the above specialists but also potentially the general public in terms of biodiversity improvement in urban environments (backyards). The Department of Conservation have indicated interest in the potential of this research for conservation efforts for skinks.

In addition this project will:

- Improve knowledge on living roof biodiversity, with national and international impact, through existing living and green roof research networks and feedback from the Vancouver conference indicates and interest in this research at an international level.

- Lead to new, healthy native lizard populations in Auckland region. Success leads to expansion of new lizard populations in de novo areas, particularly those in mammal-free, rainbow-skink free habitats (living roofs) and further afield in local parks and backyards.
- Lead to development of habitat objects (commercial potential) for use in lizard relocation projects, but particularly on living roofs.

Stage 1 of this research was just the beginning, and generated a lot of interest from a range of discipline areas. Continuation of the research through stage 2 and 3 will confirm the above potentials of the research and may lead to further opportunities for living roof research in the NZ context. A potential living roof biodiversity project relating to endangered red and yellow admiral butterflies is in development in association with Landcare Research.

Recommendations (optional)
List any specific recommendations for the teaching, learning, or research communities.

Publications and dissemination

The anticipated publications and disseminations for this stage1 of the research project are different from those anticipated in the original research application. The predominant reason for this was a number of opportunities which arose during the course of the year which offered dissemination of the research findings beyond what was originally anticipated for a stage 1 component of the project.

Other anticipated research outputs were not achieved due to the stage 1 nature of the project, where the first stage outputs were not complete enough to warrant (for example) an application for the MFE Green Ribbon Awards (an application is being made currently for the 2011 year). Some of the anticipated outputs require additional results from stage 2 to be in place prior to finalization.

The following outlines the original outputs anticipated and identifies those which were achieved in 2010.

Original Output	Additional Outputs	Status	Comment
Entry to MFE Green Ribbon Environment Awards. Category of Innovative Solutions for the Environment.		Currently being prepared for 2011.	Research was not at a stage in 2010 to apply for these awards as the entries are in April. An attempt will be made in 2011 but it may be that the research is in too early stages to be successful.
Handbook & web pages: designing single-purpose and multi-purpose NZ living roofs (stormwater, biodiversity, and aesthetics). 'Landscapes for Life': 2 pages, suitable for www, that showcase case studies.		Currently being prepared.	
A co-authored paper will be submitted to the 2012 International Living Roof Conference (a refereed conference).	A co-authored paper was accepted and presented at the 2010 Cities Alive **Type:** Conference Presentation Davies, R.B., Simcock, R., Ussher, G., and Boult, M. (2010). Elevated enclaves – living roof biodiversity enhancement through prosthetic habitats. Greenroofs.org. http://greenroofs.org/index.php/research—policy-database.	Paper presented in November 2010 in Vancouver	
A co-authored paper will be submitted to NZJ Ecology		New NZ Herpetological journal is to be published	

scientific paper: De novo urban skink habitats.		in September 2011 and the editor has indicated an interest in publishing this preliminary stage of the research. A journal article is currently being prepared.	
Handbook for urban lizard relocation, habitat creation and enhancement (seeking collaborative funding from WCC. ARC. MfE).		Funding still being sought.	
Field Workshop: management of urban skink populations with end users (ARC, TLAs, DoC, consultants, researchers).		On hold.	Research not at a stage where it is ready for inclusion in such a workshop
	Presentation to Unitec Research Symposium on Landscapes for Life research	Presentation made in	
	Invited to give presentation to Auckland University Experts Seminar Series on Living Roof research.	Presentation made in March 2011	
	Presentation to Unitec Leadership Kaleidoscope Strategy Day – example of research collaboration.	Presentation made in January 2011	
	Paper accepted and presented at the ANZASCA conference in 2010 on living roof indigenous plants and insect biodiversity components of the landscapes for life research. **Type:** Conference Presentation Davies, R.B., and Simcock, R. (2010). Islands in the Sky – Opportunities for urban biodiversity enhancement in New Zealand using indigenous living roof landscapes. ANZASCA Conference. ISBN 978-0-473-18000-3.	Presentation made in November 2010 and published proceedings.	Editor of the NZ Journal of Botany has indicated an interest in publishing this research and an article is currently being prepared.
	Invited to provide seminar presentation on research project and processes to illustrate best practice in collaborative research to Kick Start conference at Unitec.	Presentation made in Februrary 2011	
	Co-hosted with Livingroofs Aotearoa, an industry event on living roof research and biodiversity. Presented the Landscapes for Life research and then Dr Brad Bass, a living roof expert who we met in Vancouver presented latest best practice in living roof.	Presentation made in January 2011 to an audience of over 200. Youtube video of interview with Brad Bass.	

References

1. Barwick, R 1958, 'The life history of the common New Zealand skink *Leiolopisma zelandica* (Gray, 1843)', *Transactions of the Royal Society of New Zealand*, vol. 86, parts 3 and 4, pp. 331-380.

2. Brenneisen, S 2007, 'Space for urban wildlife: Designing greenroofs as habitats in Switzerland', *Urban Habitats 4*(1):27-36.
3. Cree, A & Daugherty, C H 1991, 'High rates of cutaneous water loss in nocturnal New Zealand reptiles', Unpublished report to Director, Science and Research Directorate, Department of Conservation.
4. Department of Conservation 2000, The New Zealand Biodiversity Strategy, February.
5. Freeman, A 1994, 'An ecological study of the lizard fauna of Kaitorete Spit, Canterbury', Thesis submitted in partial fulfilment of the requirements for the Degree of Master of Applied Science, Lincoln University.
6. Freeman A 1997, 'Comparative ecology of two Oligosoma skinks in coastal Canterbury: a contrast with central Otago', *New Zealand Journal of Ecology*, vol 21, no. 2, pp. 153-160.
7. Gill, B 1976, 'Aspects of the Ecology, morphology and taxonomy of two skinks (*Reptilia Lacertailla*) in the coastal Manawatu area of New Zealand', *New Zealand Journal of Zoology*.
8. Grant, G 2007: 'Extensive greenroofs in London', *Urban Habitats 4*(1):51-65
9. Howard, R, Williamson, I & Mather, P 2003, 'Structural aspects of microhabitat selection by the skink *Lampropholis delicata*', *Journal of Herpetology*, Vol 37, 3, pp. 613-617.
10. Jones, RA 2002, *Tecticolous invertebrates. A preliminary investigation of the invertebrate fauna on greenroofs in urban London*, English Nature.
11. Lundholm, J, Peck, S 2008, 'Frontiers of green roof ecology', *Urban Ecosystems*, vol 11, no. 4, pp. 335-337.
12. Lunney, D, Ashby, E, Grigg, J & O'Connell M 1989, Diets of scincid lizards *Lampropholis guichenoti* (Dumeril & Bibron) and *L. delicata* (De Vis) in Mumbulla state forest on the south coast of New South Wales, *Australian Wildlife Research*, Vol. 16, pp. 307-312.
13. McCann, C 1956, Keys to the lizards of New Zealand, Tuatara Vol 6, issue 2.
14. Muchna, K 2009, *'Rainbow skink: invasion ecology of an introduced lizard'*, Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science, University of Auckland.
15. Montoya, I & Burns, K 2007, Community-wide character displacement in New Zealand skinks' *Journal of Biogeography* vol 34, pp. 2139-2147.
16. Neilson, Keri A 2002, 'Evaporative Water Loss as a Restriction on Habitat Use in Endangered New Zealand Endemic Skinks' in *Journal of Herpetology,* 36(3), pp. 342-348
17. Oberndorfer et al 2007 'Green roofs as urban ecosystems: ecological structures, functions and service' *Biosciences*, vol 57 (10), pp. 823-833.
18. Patterson, G 1985, *'The ecology and taxonomy of the common skink Leiolopisma nigriplantare maccanni in tussock grasslands in Otago'*, Thesis submitted for the degree of Doctor of Philosophy, University of Otago, New Zealand.
19. Peace, E 2004, *Distribution, habitat use, breeding and behavioural ecology of rainbow skinks (Lampropholis delicata) in New Zealand*, The book bindery, Thesis, University of Auckland
20. Simcock, R & Toft, R 2008, *Invertebrate Monitoring of the Waitakere Civic Centre Greenroof*, Landcare Research
21. Spencer, N, Thomas, B, Mason, R & Dugdale, J 1998, 'Diet and life history variation in the sympatric lizards *Oligosoma nigriplantare polychromoa* and *Oligosoma lineoocellatum*', *New Zealand Journal of Zoology*, vol. 25, pp. 457-463.
22. Stephens, C 2004, *'Plant succession, ecological restoration and the skinks of Stephens Island/Takapourewa*', Thesis submitted for a Masters in Science in Ecology and Biodiversity, Victoria University.
23. Tocher, M 2003, 'The diet of grand skinks (Oligosoma grande) and Otago skinks (O. otagense) in Otago seral tussock grasslands', *New Zealand Journal of Zoology*, Vol. 30, pp. 243-257.
24. Toft, RJ & Meurk, C & Harris, RJ & Dugdale, JS. 2004, 'Restoration of Insect Communities in an Urban Landscape: Criteria for Success', *Ecological Restoration Workshop*, Christchurch, New Zealand. 18 May 2004.

25. Towns, D 1999, *Department of Conservation Cyclodina spp. skink recovery plan 1999-2004*.
26. Towns E & Elliott G, 1996, 'Effects of habitat structure on distribution and abundance of lizards at Pukerua Bay, Wellington, New Zealand'*, New Zealand' Journal of Ecology*, vol 20, no. 2, pp. 191-206.
27. Whitaker, A 1987, 'The roles of lizards in New Zealand plant reproductive strategies', *New Zealand Journal of Botany*, vol. 25, pp. 315-328.
28. Ussher, G 2005, *Lizard protection on Shakespear Regional Park*, Auckland Regional Council, Auckland, New Zealand.
29. Van Winkel, D 2009, 'Shakespear Regional Park lizard monitoring report', p 50, Auckland Regional Council, Auckland.