# Biodiversity Research on Green Roofs:

# Draft Final Research Protocol

# May 2009

## Introduction

Green Roofs for Healthy Cities is dedicated to advancing our understanding of green roof and wall performance at the product, building system/site and community wide scale. In February 2008, we convened a Biodiversity Roundtable in Toronto, Canada of various experts to determine whether we could pull together a protocol to assist with the development of regionally relevant green roof biodiversity.

The workshop and the subsequent draft protocol was prepared by Dr. Brad Bass Chair, Green Roof for Healthy Cities, Research Committee 2007 – 2009, Adaptation and Impacts Research Division, Centre for Environment, University of Toronto. We are seeking additional input on this draft protocol until July 31, 2009. If you wish to comment on the draft please contact Dr. Brad Bass by e-mail: **Brad.Bass@ec.gc.ca**.

## Background

Green roofs can create habitat for plants, microorganisms, insects, and birds (Getter and Rowe, 2006). A biodiversity study of seventeen green roofs in Basel, Switzerland found 78 spider and 254 beetle species. Eighteen percent of those spiders and 11% of the beetles were listed as rare and some were considered as endangered (Brenneisen, 2003). In Berlin, Darius and Drepper (1984) found grasshoppers, white grubs, beetles, and a high number of mites on 50-year old green roofs, and in Switzerland, nine orchid species and other rare and endangered plant species were found on a 90-year-old green roof (Brenneisen, 2004). In the UK, green roofs have been found to provide habitat for the Black Red Start, and endangered bird species (Gedge, 2003). In northeastern Switzerland, nine orchid species and other rare and endangered plant species existed on a 90-year-old green roof (Brenneisen, 2004). In addition, many birds have been recorded using green roofs in Germany, Switzerland, and England (Brenneisen, 2003; Gedge, 2003). Two years of observations on a green roof located on the York University campus in Toronto, Ontario indicated an increase in biodiversity since the initial installation.The green roof on top of a Ford assembly Plant, in Dearborn, Michigan became home to 29 insect species, seven spider species, and two bird species within the first two years (Coffman and Davis, 2005).

The Biodiversity on Green Roofs Roundtable, February 21, 2008, raised several questions about conducting biodiversity research on green roofs. This goal of the workshop was to begin the development of a protocol for conducting this type of research. After the initial meeting, this protocol was later developed over two subsequent meetings, focused on covering six questions. The first meeting covered the first three questions and took place on April 11, 2008. The second meeting occurred on August 12, 2008 and covered the latter three questions. A list of attendees for each workshop is included in Appendix 1.

Although the list varied between workshops, the final draft protocol has been reviewed by all attendees and the members of the Green Roof for Healthy Cities' Research Committee, which also includes some of the biodiversity research colleagues in Europe.

**Scope of the Protocol: Green Roofs and Benefits**

The purpose of these meetings was not to reiterate the definition of a green roof but for the attendees to agree upon the most common definitions of a green roof, focusing on biodiversity. Other benefits were discussed as being important to the research, but only as they related to biodiversity. The participants' experience also extended to green walls and breathing walls, and for the most part, this protocol would extend to those technologies as well. Although it may not have an impact on the protocol, the participants did recognize that there are green roofs that have emerged out of other gardening initiatives on roofs, such as the 401 Richmond Street project in Toronto. The time allotted for the meeting was not sufficient to discuss how these latter roofs might be included in this protocol.

**Defining Biodiversity and Some Issues for the Urban Environments**

A presentation by Eric Davies provided the participants with a common basis for discussing biodiversity and some of the issues that are unique to green roofs in an urban environment. Biodiversity is not just about counting the number of species on a roof or in any other landscape. What is in the landscape, or on the roof, comprises the structure of the ecosystem. For biodiversity, the functions associated with these structural elements are also important. For example, a bird might be a structural element, but in a particular ecosystem, its function might be seed dispersal. In maximizing biodiversity, the intent is not just to maximize the overall number of functions, but to maximize the number of particular functions. Appreciating that biodiversity is composed of both structure and function will allow for the development of research and policy for producing functional ecosystems on a roof. Functional roles correspond to the ecological niche of each structural element.

The concept of biodiversity zones or regions was deemed to be relevant for green roofs in an urban environment. Most cities can be divided into residential, industrial/commercial and green regions (parks, ravines, wetlands). These regions reflect land use designations, but will also include different types of natural habitats and may reflect different microclimatic conditions. Division of the city into different land use areas is an important feature of research existing green roofs that involves the use of replicates. The word region is being used in place of zone because land use zones have a specific meaning for urban planners.

**Issues Addressed by the Protocol**

The protocol will address six specific issues that were presented and modified during a subsequent discussion:

1. What questions should be used to focus the research? Although the most obvious question is whether biodiversity has changed, there are other questions that might change the manner of research. For example, what contribution does increased biodiversity make to the success in greening the roof, the energy conserved due to the green roof, the reduction of runoff or the ability of the roof to adapt to climate change? Some of these questions can be asked from the opposite perspective, such as, what will be the impact of climate change on green roof biodiversity?

2. Which data should be collected to answer the question?

3. What are the options for collecting these data? This question covers instrumentation, sampling protocols, etc.;

4. How do we define the quality of the data? Since all data are uncertain to some extent, how should this uncertainty be defined and quantified?

5. How should the data be summarized? Should researchers use the common biodiversity indices, the coefficient of conservation and the floristic quality index? What types of analysis should be used to interpret the data?

6. How should the results of the analysis be interpreted?

The meeting lasted three hours, which was sufficient to address the first three elements of the protocol.

**ISSUE 1: What are the research questions that are of interest for biodiversity on green roofs?**

The discussion on this issue was able to resolve four distinct and possible interrelated questions:

1) What is the relationship of the green roof to the wider environment? The wider environment includes both the built form and the natural heritage/environment of the area;
2) Identify species on the roof and their functional value;
3) How do we build ecosystems on a roof? This includes questions of function, adaptability and resilience;
4) What is the performance/utility value of biodiversity?

Question 1: What is the relationship of the green roof to the wider environment?

This question might address a number of research issues. It is important if the green roof is being designed to mimic the biodiversity in an existing area or to identify which plants would be more favourable in a specific area to understand why certain species and functions have emerged on the roof. Biodiversity zones tend to follow pre-existing land uses in built up urban areas, each of which might have microclimatic factors, major features such as a lake or airport as well as a unique mix of species and functions if species are being exported from the green roof to other urban environments. Understanding the wider environment is important to ensure the replicability of experiments or designs in different locations.

This could be a research question on its own, but is also a question that could precede any of the other three questions.

Question 2: Identify species on the roof and their functional value.

The number of different species is the first question that is usually posed in trying to quantify the biodiversity on a roof, but from the above definition of biodiversity, this would be incomplete. Adding the functional value allows for a more in-depth description, not only what is there, but why it is there. This perspective also provides a context for looking at fauna, such as birds whose function might be one of seed dispersal and use the roof but do not permanently dwell on the roof. It also is important in understanding how to design green roofs for specific species, such as the Black Red Start in London.

Question 3: How to do we design ecosystems on a roof?

Green roofs can be designed to:

- mimic certain natural heritage features in an area, provide habitat for certain types of species,
- create ecosystems that are not typically found in the area,
- recreate ecosystems that may have once existed in the area or
- design ecosystems that could exist in the future due to changes in the climate.

This raises a number of issues around function, adaptability and resilience. The design may have to incorporate certain functions or be aware of the functional value of certain species in the area. Other issues involve designing for resilience and adaptability. For example, does the loss of one species from the green roof compromise its resilience to future disturbances? How much redundancy should be incorporated into the green roof? In designing for the future, should the green roof be adaptable to current conditions or the climate that might be expected in twenty years? Can a green roof be designed so that the ecosystem, that is expected to emerge in 10–20 years, is established immediately?

Question 4: What is the performance or utility value of biodiversity?

This question addresses the linkage between biodiversity and other green roof benefits such as energy conservation or stormwater runoff. It also addresses linkages between biodiversity and success in greening the roof, maintenance and irrigation. For example, how are energy savings related to biodiversity and what is the role of the structural complexity of the terrain (to encourage biodiversity) and the use of evergreen species? This question was geared towards the relationship between biodiversity and the benefits to human users of the green roof. Questions such as whether certain features are suitable for particular species are addressed in question 3. This has also been termed the functional aspect of biodiversity.

**ISSUE 2: Which data should be collected to answer the question?**

These data are those required to answer any of the four questions in Issue 1. Essentially, they address the context for biodiversity, the attributes on the roof and what can be contributed to the roof.

Context (environment as well as building information) of biodiversity:
- location of green roof;
- building orientation;
- climate data;

- building dimensions;
- soil or growing medium;
    - depth;
    - porosity;
    - material.

Attributes of biodiversity:
- species richness;
- spill-out effects (what green roof contributes to area);
    - i.e. seeds.

Contributions to the roof:
- spill-in effects (organisms transported onto the roof);
    - local plants and seeds brought onto the roof.

The spill-in and spill-out effects provide data to go beyond species richness. For example, one functional value is that of the pollinator where the spill-in might be butterflies and the spill-out would be nectar.

**ISSUE 3: What are the options for collecting these data?**

The objective in this issue is to ensure that the data collected are credible, the results are replicable and appropriate controls are in place so that the impacts of specific changes are well understood. Biodiversity research can involve a single roof or multiple roofs. On a single roof, other studies have sampled the roof based on quadrats, or a grid where each cell is sampled in the same manner. However, to move beyond description, the recommended procedure is the randomized block design. This involves setting up different blocks, of the same area, on one roof or using multiple roofs as different blocks. One block is a control, and the other blocks could be subject to different degrees of change in one variable. On a single roof, a subset of the quadrats could be designated as blocks.

The randomized block design allows for experiments with controls of different variables. This method can be applied to all four of the questions raised in Issue 1, where an experimental protocol is required to answer these questions, but is considered the best to tackle the fourth question on the utility value of biodiversity. It will allow for statements that can relate aspects of biodiversity, such as species richness, to benefits such as stormwater runoff. It can also be adapted to roofs of different ages, allowing insight into what will happen to a roof in an area over time. This does not necessarily replace observing one roof for 10-20 years.

However laying out the time sequence in space allows each roof to be used as a block in the randomized block design.

One issue that kept emerging, and is appropriate to this section is adaptive management; that is learning by trial and error or repeated practice. In the meeting, this was sometimes contrasted as academic roofs versus practice and art versus the science. It is a method of experimentation and learning that is implicitly, if not explicitly, used by practitioners such as designers, builders or green roof managers. Each green roof is its own experiment, identifying good and bad innovations that can be ignored or included in future green roofs. For some participants, this was considered valid for conducting research while others described it as a means of prototyping a design that would eventually require a more formal research setting to provide replicable results.

**ISSUE 4: Data Quality**

Data quality refers to issues of uncertainty and is of a major concern in many fields. Two alternatives were discussed for describing uncertainty. The first was NUSAP (number, unit, spread, assessment and pedigree) developed to for decisions involving a high degree of risk and complexity. It clearly goes beyond most conventional measures of uncertainty, by incorporating some description of how the data was collected and reviewed by peers. The second approach was more typical of meteorological data and other data collected in the field. It involves descriptions of accuracy, precision, measurement protocol and scale of representation.

Neither of these descriptors are recommended at this time because they are not commonly used by the green roof research community. In addition, green roof research is in its relative infancy in comparison to other disciplines. Given the diversity of roofs in terms of design, location, age and experimental set-ups on research roofs, it is not clear whether any set of observations can be truly replicable at this stage. Issues of replicability were discussed in length because green roofs are still dynamic systems, and can change in nontrivial ways over time with or without interventions. For now, it was decided to recommend that data be collected in a manner that is amenable to statistical analysis, which in turn can provide some indication of accuracy, precision and the risk of error.

**ISSUE 5: How Should Data be Summarized?**

It is quite common in North American biodiversity studies to summarize the data with indices such as the Coefficient of Conservatism (CC) and the Floral Quality Index (FQI). The CC measures the degree to which a plant should be located within its natural habitat, usually a remnant habitat, or is tolerant of habitat disturbance (Masters 1997). The index ranges between 0 and 10, with 10 indicating that the species is restricted to these remnant habitats and 0 indicating the species is tolerant of disturbance and can be considered a habitat generalist. In a recent evaluation of biodiversity on a green roof, the Toronto and Regional Conservation Authority (TRCA)[1] altered the definition of this index, scaling habitat dependence from 0–5 and adding a index for sensitivity to development, also ranging from 0–5. The two indices are added together to produce the CC (TRCA 2006).

The FQI is an index that takes into account both species richness and the degree to which a plant should be located within its natural habitat. It is derived by weighting the CC to the squared-root of the number of native species n.

$$\text{FQI} = \text{average CC} * \sqrt{n}$$

The use of these indices on green roofs appears to be somewhat restricted, meaning they are not considered useful tools to describing biodiversity in all cases. In particular, these indices may be very useful for research involving colonization of a green roof that are used to preserve native species. The FQI in particular is deemed a good indicator of remnant species, and a high value is useful in identifying green roofs for species preservation, particularly of flora. A low FQI might indicate that the green roof should be evaluated for other benefits besides biodiversity.

There are several restrictions on using these two indices:

- They are both designed for flora, although each could probably be adapted to include fauna;
- the FQI provides no indication of resilience. The CC may be better suited for this, in that it provides some measure of the adaptability of the plants to disturbed environments;
- both of these indices may not be useful in a policy context, and may be hard to interpret by the policy community;
- the indices, particularly the FQI, may be stand alone not allowing for the interpolation of other problems or solutions;
- both indices are sensitive to how the green roof is managed, and may not be useful descriptors under intensive management regimes;
- two identical scores on different roofs may not mean the same thing due to differences in management, green roof design and location in a large urban area.

[1] Conservation Authorities are regional bodies under the purview of regional or upper tier municipalities in Ontario, although their watersheds may cross regional boundaries.

There are other indices that can be used to summarize biodiversity. An older index is the Shannon-Weaver measure of entropy (Reference). This index was originally used to quantify the amount of uncertainty, redundancy and information in a message. It is formulated from the probability of occurrence of different events where $p_i$ is the probability of event i. The index is formed by multiplying each $p_i$ by the logarithm of itself and taking the sum of all observations.

$$\text{Diversity} = -\sum_{i=1}^{n} p_i \log p_i$$

The sum is then multiplied by -1 or another weight. This index has been used by Kadas (2002) and Brenneisen (2003) in green roof studies. Coffman (2007) found that this index can still be a fair indicator for green roof biodiversity, but recommends the Rènyi indicies (Reference), a modification of the basic Shannon index for multiple roof comparisons Coffman cites two other indices for consideration:

1. The Simpson Index when observing common species;
2. Evenness which is a measure of observed diversity versus the maximum diversity in a given area.

Another index is used by the Netherlands Environmental Assessment Agency (NEAA) is the Mean Species Abundance (MSA). The MSA is equal to 0% for a non-natural area or an intensively used area subjected to other pressures such as nitrogen deposition or climate change. The MSA is equal to 100% in the case of a completely natural remnant having no external pressures. For instance, irrigated agriculture has an MSA of 5%, whilst agroforestry earns an MSA of 50% (MNP, 2008). One advantage of the MSA can be used to project future trends in biodiversity (Alkemade et al., 2006). Other indices cited by the NEAA include the Species-Area Curve (Sala et al., 2000) and the Biodiversity Intactness Index (Scholes and Biggs, 2005).

The advantages and disadvantages of various indices that could be used for summarizing biodiversity are described in the table below.

| Indices of Biodiversity | Characteristics | Advantages | Disadvantages |
|---|---|---|---|
| (CC) Coefficient of Conservatism | Degree to which a species can be away from its natural habitat | Better suited in describing resilience other than FQI. Shows how well a plant adapted to a disturbed environment. | Not useful in policy context. Value depends on green roof management, roof design, and location in large urban area |
| (FQI) Floral Quality Index | Species richness and the degree to which it is located near its native habitat **FQI = CC * √n, n= num. of native species** | Describes species richness | Not useful in policy context. Depends on green roof management, roof design, and location in large urban area. Not suited for measuring resilience. |
| (MSA) Mean Species Abundancy | Classifies area as natural or non-natural. 0% and 100% represents non-natural and natural areas respectively. | Projects future trends in biodiversity | This index may not be well-known by many researchers in North America. |
| Shannon Weaver Index | Older index used to measure entropy. This index was originally used to quantify the amount of uncertainty, redundancy and information in a message. Measures species richness(number of species) and abundance (Number of individuals) | Useful for comparing green roofs for biodiversity or in assessing relationship between biodiversity and other benefits. | It is a relative measure of biodiversity comparing to the same roof at a different time or to another green roof. |
| Simpson's Diversity Index | The probability of randomly selecting two individuals from the same species. Takes into account number of species and abundance of each species. | Useful for comparing extensive roofs | |
| Renyi Index | It is the family of functionals for quantifying the diversity, uncertainty or randomness of a system | Useful for comparing roofs for biodiversity or in assessing relationship between biodiversity and other benefits | It is a relative measure of biodiversity comparing to the same roof at a different time or to another green roof. |

## ISSUE 6: How Should the Data be Interpreted

This question should be answered within the context of the four research questions posed at the beginning of this protocol (see Issue 1).

Question 1: What is the relationship of the green roof to the wider environment?

In assessing this relationship, the summary indices need to be interpreted within the context of the wider environment, current and projected future climate conditions, building density, other prominent landscape factors, and threats to biodiversity such as invasive species. One important issue in the wider context is whether the green roof is being colonized and from where because it may be exporting species to other urban areas and providing habitat (either planned or unplanned) to birds and/or insects. Answering this question often requires observations of roof coverage over multiple years.

The two indices, CC and FQI, may have some use in this question. For example, a high CC value, indicating the presence of species that are closest to an undisturbed environment, indicates one type of relationship with the wider environment (perhaps the green roof as an isolated island); whereas a low CC value would suggest a higher degree of species resilience and adaptability to disturbed environments, perhaps, suggesting a higher degree of colonization from the wider urban environment. The Evenness Index may be particularly useful in illustrating the relationship of the roof to its wider environment. The indices used by the NEAA have not been used in green roof studies, and it is not clear how applicable they will be to a green roof. However, these indices may prove to be quite useful when looking at multiple roofs as part of a cities natural heritage system and projecting future trends in urban biodiversity, particularly under climate change

Question 2: Identify species on the roof and their functional value.

The use of indices may be of limited value in answering this question. In answering this question, what species are absent might be as important those present on the roof. This data can also be interpreted in terms of resilience, stability and maintenance. For example, green roof biodiversity studies in the Switzerland (References), US (References) and the UK (References) have identified spiders as an important indicator species of biodiversity. Arthropod (spider) biodiversity has been found to improve ecological function, community longevity and resilience while decreasing maintenance and plant replacement costs (Clark and MacArthur, 2007; Kadas, 2006).

Question 3: How to do we design ecosystems on a roof?

It is not clear that either the CC or the FQI would be of much value in this type of question, but some of the other indices, such as the Simpson Index and the Shannon-Weaver Index, might be of greater utility. The Simpson Index is particularly useful for very shallow extensive roofs that may provide suitable habitat for common species (Coffman 2007). The Shannon-Weaver Index has already been used in studies that lead to new green roof designs (Brenneisen, 2003, Kadas, 2006). However, these indices are of more limited use in designing specific ecosystems, such as a tall-grass prairie, where the long-term presence of specific species is of particular importance.

Question 4: What is the performance or utility value of biodiversity?

Indices such that are straight measures of biodiversity, such as the Shannon-Weaver or the Rènyi indicies, may be quite useful summary measures in comparing roofs and teasing out relationships between biodiversity and heat flux or stormwater retention. However, the use of any index will be of limited value as other features that are linked to higher biodiversity may be of equal or greater importance. For example, uneven terrain and evergreen shrubs may support a higher level of biodiversity and may also lead to improved energy conservation, especially during the winter when the terrain and shrubs reduce wind speed over the roof. Although these features may be highly correlated with biodiversity, a high degree of biodiversity would not necessarily indicate either of these two features.

In summary, biodiversity is a relatively recent term to be defined within the field of ecology. Green roofs, typified by a shallow growing medium, harsher climatic conditions, management intervention, height and isolation from other natural areas, represent a different environment in most urban areas and are also a recent area of study. As such, interpretation of observations will always be somewhat obscured by these other factors. What may be standard practice in field ecology, may mean that a better understanding of our data will emerge as we complete additional observations on a multitude of different green roofs covering a broad geographic range.

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## Appendix 1:  List of Attendees at Each Workshop

### Meeting One, Toronto Botanical Gardens

Attendees

- Wolfgang Amelung – Genetron Systems, Inc
- Brad Bass –Adaptation & Impacts Research Division, Environment Canada at the Centre for Environment at University of Toronto
- Sam Benvie – University of Manitoba
- Monica Contreras – Urban Space Property Group
- Cathy Cox - Toronto Botanical Gardens
- Eric Davies – Gross Lab, EEB, University of Toronto
- Mart Gross – Professor of Conservation Biology, Department of Ecology and Evolutionary Biology (EEB) University of Toronto
- Elio Guarionex  – Centre for Biological Research Centre for the Northwest. Baja California, Sur, Mexico
- Steven Peck, Chair, Green Roofs for Healthy Cities
- Shazia Husain –Adaptation & Impacts Research Division, Environment Canada at the Centre for Environment at University of Toronto
- Ifteckharul Islam – Adaptation & Impacts Research Division, Environment
- Erin MacKeene –Urban Space Property Group
- Stacey O'Malley – Gross Lab, EEB, University of Toronto
- Kelly Snow – Environmental planning, City of Toronto
- Paul Tripodo - Credit Valley Conservation Authority
- Canada at the Centre for Environment at University of Toronto
- Margo Welch –Toronto Botanical Gardens

### Meeting Two:  University of Toronto

Attendees

- Wolfgang Amelung – Genetron Systems, Inc
- Brad Bass –Adaptation & Impacts Research Division, Environment Canada at the Centre for Environment at University of Toronto
- Sam Benvie – University of Manitoba/Ryerson University
- Alessandro Caroti – St. Elizabeth High School, Thornhill Ont
- Beth Anne Currie – Environment and Health Consulting
- Hitesh Doshi – Ryerson University
- Mart Gross – Professor of Conservation Biology, Department of Ecology and Evolutionary Biology (EEB) University of Toronto
- Webnesh Haile – Gross Lab, EEB, University of Toronto

- Sarah Hasnain – Gross Lab, EEB, University of Toronto
- Ellie Jin – St. Elizabeth High School, Thornhill Ont/University of Toronto Summer Mentorship Program
- Eleni Koukidis –Adaptation & Impacts Research Division, Environment Canada at the Centre for Environment, University of Toronto
- Iryna Krukovets –Adaptation & Impacts Research Division, Environment Canada at the Centre for Environment/Dept of Biology at University of Toronto
- Stacey O'Malley – Gross Lab, EEB, University of Toronto
- Jordan Richie – Green Roofs for Healthy Cities
- Kelly Snow – Environmental planning, City of Toronto
- Serguei Stremilov –Adaptation & Impacts Research Division, Environment Canada at the Centre for Environment, University of Toronto
- Paul Tripodo - Credit Valley Conservation Authority