Urban reconciliation ecology: The potential of living roofs and walls

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ABSTRACT

Reconciling human and non-human use of urban regions to support biological conservation represents a major challenge for the 21st century. The concept of reconciliation ecology, by which the anthropogenic environment may be modified to encourage non-human use and biodiversity preservation without compromising societal utilization, potentially represents an appropriate paradigm for urban conservation given the generally poor opportunities that exist for reserve establishment and ecological restoration in urban areas. Two habitat improvement techniques with great potential for reconciliation ecology in urban areas are the installation of living roofs and walls, which have been shown to support a range of taxa at local scales. This paper evaluates the reconciliation potential of living roofs and walls, in particular highlighting both ecological and societal limitations that need to be overcome for application at the landscape scale. We further consider that successful utilization of living roofs and walls for urban reconciliation ecology will rely heavily on the participation of urban citizens, and that a ‘citizen science’ model is needed to facilitate public participation and support and to create an evidence base to determine their effectiveness. Living roofs and walls are just one aspect of urban reconciliation ecology, but are particularly important ‘bottom-up’ techniques for improving urban biodiversity that can be performed directly by the citizenry.

1. Introduction

‘Unless one merely thinks man was intended to be an all-conquering and sterilizing power in the world, there must be...some wise principle of coexistence between man and nature, even if it has to be a modified kind of man and a modified kind of nature. This is what I understand by conservation’ (Elton, 1958; p. 145).

Charles Elton’s ‘wise principle of coexistence’ is above all one of practicality: how to live well in and with the non-human world. The necessity of biodiversity for the continuance of our species is well established, as is our reluctance to reduce land and resource use at scales that would significantly retard biodiversity loss (Tilman, 2000; Gaston and Spicer, 2004; Balvanera et al., 2006). Biological conservation still largely focuses on ‘non-use’ land (Redford and Richter, 1999; Andelman and Willig, 2003), which consists of areas set aside for preservation from development or direct use (‘reserves’), and the restoration or rehabilitation of degraded ecosystems (e.g. Dobson et al., 1997; Andelman and Willig, 2003). Rosenzweig (2003a, 2003b) has demonstrated that the global land area available for reservation and restoration, by itself, is insufficient to prevent the forthcoming (or indeed current) extinction cascade (see also Rosenzweig, 1995; Dodds, 2009).

As a more realistic and practical solution, Rosenzweig (2003a, 2003b) proposed a ‘third strand’ of conservation (alongside reserves and restoration) termed ‘reconciliation ecology’. This is the modification and diversification of anthropogenic habitats to support a greater range of species, without compromising the land use. This approach is different from ‘setting aside’ land that is associated with some forms of ‘ecologically friendly’ land use, for example the conservation buffers and headlands of agricultural landscapes (e.g. Dover, 1997); and separate from ecological restoration or rehabilitation as it does not attempt to re-create or simulate a previous ecosystem state or condition (see Francis, 2009).

The application of reconciliation ecology is particularly relevant to cities, which: exhibit highly modified and cosmopolitan biodiversity that is often (though not always) lower than the pre-urban ecosystem (e.g. Soulé, 1990; Kuhn and Klotz, 2006; Pauchard et al., 2006); contain the majority of the human population and are therefore where most people interact with the non-human environment (Miller, 2005); and are the centres of national and international political, economic and cultural power. Lundholm and Richardson (in press) have recently argued for greater consideration of artificial urban habitats such as walls and pavement as ‘analogue’ habitats that can support species from comparable natural habitats (in this case rock pavements and cliffs), but that may not be...
able to colonise such habitats because of limits to their dispersal capabilities. These habitats may also be improved using ecological engineering techniques, of which living roofs and walls are key examples. Living roofs and walls have demonstrated varied environmental benefits, including the capacity to support a range of species (Grant, 2006; Kadas, 2006; Köhler, 2008; Dunnett et al., 2008), though spatial parameters such as habitat size and configuration are generally not considered (Oberndorfer et al., 2007).

Conservation in cities has been integrated into urban planning for decades, and has demonstrated the need for spatially-explicit approaches to habitat creation (e.g. Colding, 2007). The planning and management of, for example, urban greenways (connected vegetated or ‘environmentally pleasant’ landscape corridors; see Imam, 2006), requires a top-down approach made possible only by the cooperation of politicians, urban planners, ecologists and landscape engineers. Although some reconciliation (habitat enhancement) techniques may also be top-down (e.g. the creation of habitats in public parks and recreational spaces, the planting of vegetation along urban infrastructure), reconciliation will rely much more on localised and coordinated efforts of a large number of people and organisations with high levels of spatial, social and economic diversity, for example the installation of living roofs and walls (Fig. 1). These are valid reconciliation techniques as they do not prevent (indeed may enhance) human use of the space, but also encourage use by other species. It has been demonstrated that such efforts can encourage the use of habitats by species at local scales (e.g. Grant, 2006; Schrader and Böning, 2006; Valtonen et al., 2007), though a central question for biological conservation is whether such efforts will support species populations at the landscape scale, allow populations to remain resilient in the face of disturbance and stochastic change, and therefore achieve the reduction of biodiversity loss that is the aim of reconciliation (Collinge, 1996; Rosenzweig, 2003b; Colding, 2007; Lindenmayer, 2005). In this paper we review the potential biodiversity benefits of living roofs and walls, highlighting research gaps that relate to reconciliation ecology at the landscape scale, before discussing socioeconomic limitations that may prevent the installation of living roofs and walls within the urban landscape.

We also consider that successful utilization of living roofs and walls for urban reconciliation ecology will rely heavily on the participation of urban citizens, and outline a ‘citizen science’ model to create an evidence base to determine their effectiveness.

2. Living roofs and walls in urban landscapes

2.1. Background and definitions

The planting of vegetation on the roofs of buildings has taken place since antiquity as an architectural and horticultural practice (Oberndorfer et al., 2007; Dunnett and Kingsbury, 2008), but it is only recently that such designs have been used to attempt to mitigate the loss of species from urban regions (Brenneisien, 2006; Oberndorfer et al., 2007), and that scientific analyses of living roofs have taken place (e.g. Grant, 2006; Schrader and Böning, 2006; Oberndorfer et al., 2007). Living roofs (see Table 1 for a clarification of terminology) are usually constructed on pre-existing roofs, though many new buildings incorporate them into their design. They usually consist of: (1) a root resistant membrane that runs over the surface of the roof material to prevent root damage; (2) a drainage layer, which may or may not also act as a water reservoir for plant use; (3) a filter membrane, which prevents fine sediments from infiltrating into the drainage layer and being removed from the substrate; (4) a sediment layer varying in material and depth, composed of inorganic material with some (usually <20%) organic matter; and (5) a surface vegetation layer that can be seeded, planted, turfed, left to colonise naturally, or any combination of these options (Bates, AJ, pers. com).

Much of the environmental and ecological variation found in living roofs depends on the type of substrate used (along with type of planting, roof age and roof size; Schrader and Böning, 2006), and a wide range of options exists that can be tailored to specific habitat requirements (Dunnett et al., 2008).

Green facades (see Table 1) have historically been used mainly for ornamental or horticultural purposes, and involve the establishment of climbing vegetation which is rooted in the ground or planters, and which is then trained to grow directly on wall surfaces or on an overhanging wire or trellis framework (Dunnett and Kingsbury, 2008; Köhler, 2008). Living walls are distinct from green facades in that they support vegetation that is either rooted on the walls or in substrate attached the wall itself, rather than being rooted at the base of the wall, and as a consequence have been likened more to vertical living roofs (Dunnett and Kingsbury, 2008; Köhler, 2008). The walls of buildings are most suited to living wall systems that use hydroponic technology to support plants that are kept physically separate from the wall, for example a drip-feed irrigation system that keeps moist a growing medium placed on the wall but kept separate from the construction material by a waterproof membrane (Dunnett and Kingsbury, 2008), and thereby maintains the integrity of the wall structure. These are sometimes constructed on indoor walls (termed ‘biowalls’; Table 1) for aesthetic and horticultural purposes (Dunnett and Kingsbury, 2008). This kind of living wall technology is often modular, allowing plants to be grown on individual sections before mounting, and facilitating easy replacement if necessary. Alongside the modular design, an alternate design is the use of a thin (1 cm) layer of PVC and felt applied to a light metal frame on the wall surface supplied with water, which represents a lightweight cover that is also separate from the wall and therefore prevents roots penetrating wall surfaces; this is demonstrated in the ‘Vertical Garden’ walls pioneered by Blanc (2010). Köhler (2008) notes that living wall systems do not rely on a limited range of climbing flora to the same extent as green facades, and allow a far greater range of species to be planted on the wall surface; this increases the potential for utilising living walls for reconciliation, as species may be planted to
address specific functions that may be missing in the urban environment, for example the planting of herbs such as thyme (Thymus spp.) to support key pollinators. However, despite observations that living walls support a range of fauna, this is mainly anecdotal and has not been investigated in any depth (Köhler, 2008; Weinmaster, 2009).

2.2. Availability of space for living roofs and walls

As living roofs and walls essentially create habitat on land that is being directly used by humans as living space, they are a good example of the practice of reconciliation ecology. Their contribution may be particularly valuable as roof surfaces can represent up to 32% of the 2D horizontal surface in some urban locations (Ferguson, 2005), though of course not all roofs are flat or indeed suitable for supporting substrate and vegetation. In the Greater London (UK) urban region for example, Grant (2006) estimates that roofs cover 240 km², or 16% of the 2D land surface, while in Sacramento (USA) roofs cover a total area of 150 km², and between 19 and 23% of the 2D land surface depending on urban land use (Akbari et al., 2003). Vertical built surfaces within urban regions may also cover a substantial area, far greater than that of roof alone or the underlying land surface, though this varies with building dimensions and densities (e.g. Grimmond and Oke, 1999). For example, Darlington (1981) estimates that 0.01 km² of wall surface exists for every 0.1 km² of urban land surface within the UK. Along the 32 km of the River Thames through central London, 0.28 km² of contiguous wall surface exists, much of which is colonised naturally by vegetation (Francis and Hoggart, 2008, 2009). Consequently, there may be substantial potential for their utilisation to support living walls and encourage urban biodiversity.

The extent of suitable sites for living roofs and walls is likely to vary notably between urban regions based on commercial and cultural differences in building design, relative density of urban development, and the sizes of individual buildings (e.g. Akbari et al., 2003). This may vary at three broad spatial scales: 1) at the overall city scale, there is often, for example, a tendency for the densest built environment to be present in the core of the city, with this reducing with increasing distance from the centre and into the suburbs, with a consequent increase in e.g. vegetated habitat (Peiser, 1989; Bradley, 1995); 2) within the city, density of different building types changes according to the use of a given area (e.g. for industry, business, residences; Akbari et al., 2003; Baker and Harris, 2007); 3) within specific zones (e.g. residential) there will be notable difference in housing density, relating to the patch sizes of buildings and associated features such as gardens. These are very simplified, general patterns and will vary substantially between different cities (and relate to socioeconomic factors as noted below), but nevertheless illustrate the level of spatial complexity present in city landscapes. In particular, the potential may exist for walls to be used in combination with roofs to encourage 3D connectivity across urban landscapes, for example allowing invertebrate species to access roofs via wall surface foliage.

Roof and wall availability will also depend on spatial socioeconomic patterns within urban regions. Socioeconomic status may be a key indicator of reconciliation potential as this is correlated to important factors such as housing density, willingness to pay for environmental improvements, patterns of home ownership and other social factors such as level of education (e.g. Jargowsky, 1996; Li and Wu, 2006; Troy et al., 2007). As Kinzig et al. (2005) note, groups with higher economic status can devote more resources to ‘creating their ecological ideal’ (p.2). Some cities may have more
spatially-explicit disparities between socioeconomic status than others, for example those that maintain informal housing created by high levels of immigration (Forman, 2008; United Nations Human Settlements Programme, 2008). Such areas may be densely housed with little infrastructure, taking up less land area but also limiting roof and wall reconciliation options. In contrast, more affluent areas (e.g. N America) may be (or have been) subject to greater sprawl, or the urbanisation of land with low-building density areas, which fragment natural habitat, but offer more opportunities for reconciliation. Relationships between socioeconomic status and general receptivity to conservation have yet to be established, though Gaston et al. (2007) for example found that socioeconomic status (those employed in professional, business and administrative employment vs. those not) did not affect trends of wildlife gardening in the UK.

2.3. Biodiversity benefits and limitations of living roofs and walls

Much of the scientific assessment of living roofs and walls has focused on the benefits they provide to the urban microclimate, including storm water management, cooling buildings and their environs, and removing pollutants from water and air (e.g. Oberndorfer et al., 2007; Köhler, 2008) though they can be designed to support particular species of conservation concern (Grant, 2006), and to provide habitat for biodiversity in general (Getter and Rowe, 2006; Oberndorfer et al., 2007). As an ecological engineering technique most extensive living roofs (those designed to support biodiversity) are essentially designed to simulate brownfield ecosystems, which have proven of notable ecological value in recent years (Wheater, 1999; Jones, 2003; Schadek et al., 2009). Some are covered in Sedum mats, others may be sown with wildflower seeds after installation, or may experience direct planting; such vegetation may remain on the roof indefinitely and is often selected to cope with the particular roof environment, e.g. stress-tolerating species that can cope with dry, nutrient-poor substrate (Emilsson, 2008). However, a substantial benefit of living roofs to urban biodiversity comes from their capacity to act as habitat for colonising species. There are relatively few investigations of spontaneous colonisation of plant species on living roofs over both short and long timescales, though Dunnett et al. (2008) documented 35 colonising species on a single experimental living roof in Sheffield, UK, over 2004–5, with greatest abundance and diversity of colonists being found on sections of the roof with a substrate depth of 10 cm. Most of the species found were agricultural weeds or ruderals common to disturbed sites, all dispersed either by anemochory or zoochory (e.g. via birds); a trend that may be anticipated for urban living roofs in general, though this does not lower their biodiversity and functional potential. Interestingly, a wide range of growth forms were found in the colonists, from annual and perennial herbs to grasses, shrubs and trees. Although plants with larger morphologies and resource requirements such as trees are unlikely to establish or survive over long periods (Emilsson, 2008), the presence of a wide range of different functional typologies in the urban seed rain means that the potential spontaneous biodiversity of urban roofs may be quite high, if appropriate roof habitat can be engineered.

Living roof habitats, probably due to their limited size, primarily benefit organisms with small body sizes, that have the capacity to disperse easily, and either have low resource requirements that mean they can complete their life cycles on the roof (e.g. drought tolerant flora), or have more general resource requirements that mean they can utilise the habitat as part of their wider range (e.g. bees and wasps). Living roofs are well documented for their support of spiders, beetles, wasps, ants and bees, and several studies note that rare invertebrate taxa from the above groups can be found on roofs, including some with very specialised niches (Grant, 2006; Kadas, 2006). Invertebrate diversity can be particularly high; for example Kadas (2006) found over 200 species when sampling only Araneae, aculeate Hymenoptera and Coleoptera on living roofs in London, UK.

Species that do not disperse easily or are not vagile are less likely to benefit from living roofs unless they are deliberately introduced. For example, living roofs do not generally support earthworms within their soil fauna as they are unable to colonise naturally and most substrates are too shallow to support them (a substrate of less than 12 cm is considered unsuitable; Schrader and Bönig, 2006), with the result that other soil organisms become more populous, such as Collembolans (Schrader and Bönig, 2006). Brenneisen (2006) also notes that although living roofs may support many species of spider, the European members of the Atypus genus were not found on roofs in Switzerland as opposed to terrestrial habitats, presumably due to restricted vagility. Larger organisms (including those that move around the landscape easily) are less likely to nest or breed on living roofs, though they may use the habitat temporarily, for example during foraging (Baumann, 2006). One high-profile use of living roofs has been to provide habitat for bird species that are rare in the urban environment, such as little ringed plover (Charadrius dubius) and northern lapwing (Vanellus vanellus) in Switzerland, and black redstarts (Phoenicurus ochruros) in the UK (Grant, 2006). However, although there is evidence that such bird species utilise living roofs as nesting as well as foraging habitat, there is so far limited evidence that they act as successful breeding sites (Baumann, 2006), though monitoring has often not taken place for very long and so breeding potential cannot be accurately determined.

2.4. Ecological engineering of living roofs and walls for reconciliation ecology

Most living roof design is based on the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) Guidelines (Guidelines for the Planning, Execution and Upkeep of Green Roof Sites; FLL, 2002), which advises on substrate type, depth and planting regimes, among other aspects of design. Advances in living roof design are creating wider possibilities for reconciliation ecology. The use of varying substrate materials to provide different pH values, moisture availability and particle size distributions, alongside additions of organic matter and mycorrhizal inoculations (Molineux, 2010) or moisture-retaining fabrics (Dvorak and Volder, 2010), may increase resource availability and habitat heterogeneity and facilitate the colonisation of roofs by a wider range of organisms, as well as (to some extent) the replication of natural or semi-natural habitat. Molineux et al. (2009) for example found an average pH value of 8.5 for a substrate of clay pellets compared to 11.8 for carbonated limestone quarry waste pellets, and that addition of 25% organics (50:50 conifer bark compost and soil) was optimum to support plant growth and reduce shrinkage of the substrate. Variations in particle size, pH, moisture storage, substrate depth and micro-topography are likely to reflect differences in the plants and invertebrates that will colonise roofs and therefore the types of species that will be supported via such reconciliation techniques.

Recently there have been suggestions that living roofs could be used to replicate ecosystems (or a subset of species from such ecosystems) of priority concern for biodiversity conservation, within a given region (e.g. Sheffield Local Biodiversity Action Partnership, 2010). Examples within the UK include lowland heathland and lowland dry acid grassland, while Dvorak and Volder (2010) note that living roofs may be used to support species lost from natural grassland habitats within agricultural areas in North America. In some cases the preservation of viable populations of such species may not be feasible; despite the intention to replicate...
heathland on living roofs in the UK for example, many typical heather species (Erica spp., Calluna spp.) require acidic conditions (3–4 pH; Grime et al., 2007), while the UK industry red-brick standard is alkaline (9.7), and the addition of organic matter to lower pH is unlikely to result in conditions suitable for the widespread maintenance of these species, though some establishment is certainly possible (Köhler, 2006). Low (c.4.5) pH values have for example been found on living roofs in Germany in locations prone to acid rain (Emilsson, 2008), though most roofs tend towards neutral values over time (for example Emilsson (2008) notes that gravel roofs built in the nineteenth century maintain approximately neutral values). This is also reflected in the FLL guidelines, which recommend neutral conditions (6.0–8.5).

Engineering roofs to support a specific threatened or declining species or suite of species can be achieved, but may require very specific use of substrate, depth, planting regimes and management. This raises an interesting point: whether living roofs should be engineered to replicate ‘natural’ or semi-natural habitats at all, or whether they should be used as a tool to create spontaneous, novel ‘recombinant’ assemblages (Hinchliffe and Whatmore, 2006) that are common in urban ecosystems. To follow the principle of reconciliation ecology as opposed to the traditional preservation or restoration paradigms, engineering the roof ecosystem so that a non-specific but varied and functional assemblage of species can colonise is perhaps the best approach, particularly given the increasing acknowledgement of novel ecosystems (Hobbs et al., 2006) and the limitations of trying to hold onto a culturally constructed idea of what has been (or is being) lost. Lorimer (2008) for example notes that urban conservationists utilising living roofs have much greater ‘room for experimentation than is generally granted to rural conservationists, and can tailor their hybrid coconstructions to create novel spaces’ (p.2049). Exploration of the possibilities of living roofs should not be constrained by conventional conservation paradigms.

Living roofs are of course highly variable in their sizes, elevations, shapes, and styles of construction, all of which are likely to influence their capacity to support biodiversity (Oberndorfer et al., 2007; Emilsson, 2008). The importance of the species/area relationship in determining the capacity for living roofs to support biodiversity has been noted by Oberndorfer et al. (2007), and studies have noted the importance of construction style (substrate, plantings) on the biodiversity and communities found on living roofs (e.g. Emilsson, 2008). Quantification of these effects remains an important research gap for urban reconciliation ecology. Certainly at the local scale, some of the benefits of living roofs have been determined, and Bates et al. (2009) recommend that ecologically-designed living roofs should contain low nutrient levels to prevent competitive dominance, diverse substrate types and depths, areas of bare or sparsely vegetated substrate, areas of coarse substrate and disturbance refugia such as wood or stone piles. These are sound recommendations, but it is important to determine the limitations of the support that living roofs can offer to biodiversity, in terms of 1) the taxa that they can support given the limitations of design and structure (e.g. limits on substrate depth); 2) the limitations of their size, i.e. whether the ‘patch size’ of such roofs will generally be below a threshold that precludes some taxa from using them; 3) whether the spatial patternning of living roofs within the urban matrix may enable metapopulations to exchange individuals and therefore colonise roofs in which species have been extirpated, and 4) whether metapopulations are resilient and may therefore be persistent within the urban region, so that living roofs may genuinely support the species indefinitely (Oberndorfer et al., 2007). Living walls may possibly be linked to roof developments to provide a supplementary role, as they too suffer from limitations of, for example, substrate depth. These aspects of living roofs and walls need to be evaluated before their potential benefits as a technique for reconciliation ecology can be properly assessed and appropriately refined.

2.5. Socioeconomic barriers to the installation of living roofs and walls

Alongside the structural considerations noted above, potential socioeconomic barriers to the utilisation of living roofs and walls for reconciliation ecology exist. First, they require some monetary investment, usually up to £100 (c.$150) per m² (The Green Roof Centre, 2010) for retrofitting of living roofs, for example. Although this is not a prohibitive cost, it does require the roof owners to value the potential roof benefits enough to make this initial outlay. This may frequently not be driven by biodiversity concerns but rather the potential benefits to roof materials by, for example, protecting the waterproofing membrane from weather and ultra-violet radiation. Where living roofs are incorporated into building design there is greater potential for a more coordinated reconciliation effort. Some countries and localised governmental regions are very proactive in encouraging the use of living roofs; Carter and Fowler (2008) review locations where technological standards require that certain types, sizes or proportions of new buildings are required or encouraged to install living roofs, sometimes including direct or indirect financial incentives. Living walls may have higher costs (around £260 or £390 per m²) and potentially require more maintenance, which may be one reason why they are less common than living roofs.

Cultural perceptions of urban nature have also proved challenging to the construction of both living roofs and walls. For example, although many people may be supportive of living roofs on buildings, the initial terminology of ‘green roofs’ is now being downplayed as people were responding negatively to the reality of such roofs. In their extensive (and often more biodiverse) forms these roofs often do not have a lush green appearance, but are in fact similar to brownfield sites (Dunnett and Kingsbury, 2008). There is a danger that visible and accessible living roofs and walls get ‘green-washed’ in order to comply with public expectations of urban nature (Lorimer, 2008). This tendency is demonstrated in an example from Islington, London (Blunden, 2010) where a living wall installed on a children’s centre received very negative press when irregular maintenance of a water pump led to the wall becoming sparsely vegetated 4 years after installation. It was consequently regarded as an eyesore and a failure. Although this is an example on a public building paid for by public money, the same issues relating to perception of the wall and the level of success may well emerge on private buildings, particularly as such walls are very prominent within urban environments (e.g. Weinmaster, 2009). If living roofs and walls are well constructed and maintained however, they may enhance the perception and use of the host building by people, by providing contact with non-humans that may be psychologically beneficial (Weinmaster, 2009). Furthermore, living roofs are frequently inhabited by obscure and uncharismatic species and conservationists must devise creative strategies to identify flagship species for their conservation. Here some success has been achieved by linking living roofs to the habitats of rare birds such as northern lapwings (Vanellus vanellus) and black redstarts (Phoenicurus ochruros) (Baumann, 2006; Grant, 2006). A particular challenge for reconciliation ecology is in gaining support for the notion that the character and value of biodiversity cannot always be readily discerned or demonstrated, and may be counter-intuitive; and that unpleasant, untidy or ‘annoying’ biodiversity may result from reconciliation. Increased education and public awareness of this is likely to be crucial in facilitating reconciliation efforts, but this issue needs more detailed investigation.
3. Citizen science and urban reconciliation using living roofs and walls

3.1. Post-normal science and the role of citizens

Conservation (of which reconciliation is one strand) is a post-normal science (see Funtowicz and Ravetz, 1993), in that its ‘crisis’ nature means that decisions have to be taken before much rigorous scientific investigation can be performed. Much of the decision-making and application of techniques relies on practitioners who are not scientific experts or scientifically trained (Haila, 1999; Francis and Goodman, 2010). As Rosenzweig (2003b) notes, there is ‘no other branch of biological science that so involves laypeople in its front lines’ (p. 101). Although this can lead to problems of knowledge transfer within such an ‘extended peer community’ (Francis and Goodman, 2010), the availability of a potentially substantial volunteer force in urban regions (Clarkson et al., 2007) makes bottom-up approaches to reconciliation distinctly possible (Fig. 1). There is a growing recognition of this potential amongst important public and nongovernmental organisations (Cohn, 2008), e.g. the promotion of ‘Backyard Habitats’ in the USA and the encouragement of wildlife gardening and reporting in the UK (Bormann et al., 1993; Rosenzweig, 2003b; Ryall and Hatherell, 2003; Gaston et al., 2005a; Thompson, 2007; Goddard et al., 2009).

As noted above, research gaps exist regarding the design of living roofs and walls and also their landscape scale benefits and interactions. A landscape scale focus is likely to be key for reconciliation ecology: Goddard et al. (2009) acknowledge this in their call for a more coordinated landscape scale approach to wildlife gardening, noting that despite a move to ‘community-based’ conservation in many developed regions, lack of biodiversity experience, conservation knowledge and co-ordination of action between garden owners can lead to ineffective conservation efforts or, in the worst case, decisions that are detrimental to biodiversity overall but may be perceived to be beneficial (such as those based on ‘extended facts’ with no scientific validation; see Francis and Goodman, 2010). To improve the implementation of reconciliation ecology, these research gaps might best be addressed using the application of citizen science, linked explicitly to researcher and consultant expertise.

3.2. Developing a citizen science model for living roofs and walls

In urban areas, the advantages of citizen science models for reconciliation ecology are that 1) there is a substantial local human resource base to address reconciliation at varying levels, from the initial enhancement of habitat (e.g. living roofs) to monitoring them, to collating data, and general knowledge exchange between participants; 2) universities and professional scientists are often located in urban areas, adding a further locally-accessible essential resource required to some extent for the design, analysis and validation of reconciliation efforts, as well as international publication of findings so that the global community can benefit from the research; and 3) efforts are more likely to be noticed by the populace, further expanding interest in the area and promoting environmental education, which is a key element of citizen science and potentially a key strength of reconciliation ecology, in that even if species are not preserved, the raising of public awareness of the importance of biodiversity and the possibility of living alongside species even in cities represents at least a minor victory.

Citizen conservation based around ecological monitoring and assessment has been successfully linked to adaptive management decisions (see Araya et al., 2009), but so far there has been relatively limited progress in coordinating local action for habitat enhancement into a broader network. Evidence has shown that such efforts can be effective at the local scale and over short timeframes, and ’citizen scientists’ have been used for the collection of good quality data relating to, for example, invasive species (Delaney et al., 2008) and urban birds (McCaffrey, 2005). These models have been successful because they have involved some level of citizen training in appropriate skills, have used simplified techniques for data collection (e.g. species identification), paired citizens with professional scientists or facilitated informal checks to verify data quality, and have ensured that citizens feel appropriately valued and involved within the process. All of these techniques would be important for a citizen conservation model for urban reconciliation ecology using living roofs and walls. In this case, a citizen conservation model is needed such as the ‘Adaptive Citizen Science Research Model’ proposed by Cooper et al. (2007) for residential areas. This involves nested scales of action from local to regional (fine to broad) that incorporate individuals, community groups and professionals. Their actions involve the collection of both ecological and sociological data and the adaptive management of habitats. A research-led citizen science model is most appropriate, as information on the likely success of reconciliation strategies is lacking, and there is a great need to develop a robust evidence base for future application.

Fig. 2 outlines an adaptive citizen science model for living roofs and walls within an urban landscape. In this model, academic researchers may provide advice for the ecological design of roof and wall systems, train citizens in sampling and recording methods and species ID, and may be responsible for the analysis, processing and publication of data so that the evidence base is of use to the international community. Citizens (individually or perhaps as organisations, e.g. employees of a company) provide the physical resources for the roofs and walls, and may play the most important role of monitoring the biodiversity on the roofs over time, and for data/knowledge exchange between members of the network. Consultants may be responsible for installing the roofs and walls, and advising on design, though some consultants may also be active in monitoring or data analysis efforts. Governmental agencies have a role in the network by providing suitable incentives and funding for both retrofitting and construction of new living roofs and walls. Some ‘citizen-based’ organisations exist to promote the widespread establishment of living roofs, for example Living Roofs in London, UK (LivingRoofs, 2010), or Green Roofs for Healthy Cities (GRHC, 2010) in North America. These organisations have been successful in promoting living roof installation but also the identification of research gaps and the sharing and publicising of information, and may represent a useful focus around which citizen conservation models may be constructed.

3.3. Challenges and limitations for citizen science

Citizen science models do have several disadvantages that need to be considered for reconciliation: 1) some level of (possibly quite technical or specific) education and training is required, for essential aspects such as species identification, the practical application of habitat enhancement techniques and developing an understanding of experiment design and the kinds of data required to allow valid statistical analyses to be performed and appropriate conclusions drawn; 2) often further incentives above the preservation of biodiversity will be required to encourage active and continued participation in most cases, especially at scales required to make a difference for species populations as noted above; otherwise, it is likely that only a relative few very committed individuals will be taking part. Goddard et al. (2009) note the problems in encouraging broad-scale wildlife gardening, concluding that top-down incitivation or penalisation may work but is difficult to facilitate and does not change underlying social values, understanding and
attitudes; while bottom-up approaches that utilise local residence organisations or horticultural societies would probably produce more effective results, but are unlikely to include many people or operate at scales sufficient to make a difference. Motivation for conservation (as discussed above) remains a major obstacle to overcome; 3) data collected by citizen scientists needs to be verified and of sufficient quality and quantity, which may require a substantial amount of ‘auditing’ by academics or environmental professionals; 4) initiatives such as reconciliation that focus on maintaining populations of species necessitates a sustained interest and commitment, which can be especially hard to maintain in dynamic urban societies; 5) data collection by volunteers may not be as possible as in other citizen science models, as volunteers may not have easy and ready access to roofs and walls; 6) the large number of actors involved in such schemes requires notable organisation, and establishing responsibility and commitment to this may be problematic; and 7) the model needs to be adaptive and responsive as information becomes available, meaning that participants must be willing to change or adapt their resources and activities accordingly.

Despite these limitations, citizen science models offer a useful base for developing evidence-based reconciliation activities using roofs and walls in cities at scales that are most likely to mitigate the current and future loss of biodiversity. Much of the variability in the likely success of reconciliation ecology, via the implementation of such a model, lies not just with the physical and ecological urban template upon which habitat may be enhanced, but also in the socioeconomic and cultural differences found within the citizenry. The extent to which these create a dynamic spatial landscape of attitudes and responses to reconciliation is an important area for further investigation.

4. Concluding remarks

The practice of reconciliation ecology is not of course limited to urban areas, but they do represent key ecosystems for the application of the concept (Lundholm and Richardson, in press). Living roofs and walls represent ecological engineering techniques with notable potential for reconciliation ecology, either by replicating urban (brownfield) or non-urban natural and semi-natural ecosystems (e.g. xeric grassland); or preferably by allowing spontaneous urban assemblages to form. Varied, heterogeneous designs and a landscape scale approach may both serve to maximise the biodiversity potential of roofs and walls and make urban reconciliation ecology successful. Such landscape scale approaches are difficult in urban areas due to the spatial complexity of both the physical and social landscapes, both of which are important in determining whether living roofs and walls are likely to be installed, and whether they are likely to be successful. This is particularly true for bottom-up reconciliation efforts instigated largely by the citizenry (though with some governmental support) as in the case of living roofs and walls. Co-ordination of action at the landscape scale is likely to rely on citizen science due to the amount of work involved and the timescales under consideration (e.g. for species colonisation, population monitoring), which would be beyond the scope of a typical team of academic researchers. The success of citizen science initiatives in other areas suggests that this is real possibility, and initial efforts at developing living roof communities in various parts of the world have clearly made steps in this direction.

Living roofs and walls do not represent the only techniques for urban reconciliation ecology however, and should be considered alongside enhancement of remnant or introduced recreational habitat, including private gardens, allotments and public parks; and enhancement of infrastructure, such as road and railway buffers and the planting of urban trees. Though we do not review these possibilities here, they too form part of the urban landscape that may be utilised to support biodiversity, and a coherent, integrated approach is something for urban ecologists, sociologists and planners to strive for. We urge a management of expectations though, and encourage citizens to consider that the biodiversity that emerges is likely to be in untidy, unexpected and non-traditional
forms. We consider that many aspects of Elton’s vision of conservation as ‘a modified kind of man and a modified kind of nature’ will emerge from an engagement with reconciliation ecology in urban ecosystems.

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