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Ecosystem Services Analysis in Response to Biodiversity Loss Caused by the Built Environment

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Abstract: The aim of this paper is to establish a broad overview of the impact urban areas have on biodiversity and to determine the predicted major impacts that biodiversity loss and ecosystem degradation have and will have on the built environment. Common built environment responses to these impacts will also be examined. Regenerative design that uses the ecosystem services analysis method is proposed as a way of responding to biodiversity loss while simultaneously addressing climate change mitigation and adaption in a built environment context. This is examined for potential benefits and disadvantages.

Key words: Cities, climate change, ecosystem biomimicry, ecosystem health, regeneration, regenerative design, urban.

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1. INTRODUCTION

Biodiversity can be defined as: “...the number, abundance, composition, spatial distribution, and interactions of genotypes, populations, species, functional types and traits, and landscape units in a given system” (Díaz et al., 2006: 1300). The major causes of global biodiversity loss are anthropogenic in nature and are exacerbated by ongoing climate change (Warren et al., 2013; Gitay et al., 2002), particularly because climate change accelerates habitat destruction, overexploitation and the prevalence of invasive species (Brook et al., 2008). Changes in biodiversity are of a large and increasing magnitude despite worldwide conservation efforts, and recognition that the benefits derived by humans from diverse and healthy ecosystems exceed the costs of sustaining them by a factor of between 10 and 100 (Rands et al., 2010; Sala et al., 2000). Human-caused drivers of environmental change mean that most ecosystems are in crisis or decline (Walther et al., 2002). Rates of species extinctions are currently 100 to 1000 times greater than the natural background rate, while populations of wild species are declining at a rate of 0.5 to 1% per annum on average (Chapin et al., 2000; Rockstrom et al., 2009). Estimates of the loss of health in the planet’s species since 1970 (WWF, 2010). 12% of this loss has occurred since 1992 (UNEP, 2011). Within this century, between 10 and 48% of climates that species currently exist in are projected to disappear, and between 12 and 39% of the Earth will be subjected to new climates, never experienced by the current species that inhabit the Earth (Barnosky et al., 2012). This climate change is likely to affect all species on the planet (Warren et al., 2013; Parmesan, 2006).

It is generally accepted that climate change is a significant and urgent issue that humanity must address (Walther et al., 2005). More emphasis is currently placed on climate change and its impacts than on biodiversity loss and its impacts (Norberg et al., 2012; Sala et al., 2000). This is despite there being less controversy about the reality, causes and impacts of biodiversity loss, and the fact that both issues are important and intimately related (Asafu-Adjaye, 2003; Gitay et al., 2002). Consequently, policies, laws and strategies to improve the environmental performance of the built environment focus more on climate change mitigation and adaptation than on reducing biodiversity loss. As Chapin et al. (2000) state: “Despite convincing scientific evidence, there is a general lack of public awareness that changes in biodiversity is a global change with important ecological and societal impacts and that these changes are not amenable to mitigation after they have occurred” (p.241). Several leading researchers point out that action taken to mitigate the causes of biodiversity loss and adapt to its impacts is at an inadequate level to address the problem (MEA, 2005a, 2005b; Thomas et al., 2004). Since 1992 there has been an overall decrease in money dedicated to environmental aid including biodiversity protection from bilateral and multilateral donors (UNEP, 2011).

Like climate change, global biodiversity loss is an issue of great significance that should be addressed urgently. Human survival is dependent on the diverse range of organisms inhabiting the planet (Bastian et al., 2012). This is because they affect ecosystem processes and functions, and therefore ecosystem services (Brook et al., 2013; Norberg et al., 2012; Diaz, et al., 2006). There is growing evidence that biodiversity loss has at least as significant an impact on ecosystem services as climate change.

Figure 1. Built environment drivers of biodiversity loss. [Source: author.]

The built environment contributes to biodiversity loss in at least four main ways (text in red). Light blue dots detail the ways the built environment contributes to these main causes of biodiversity loss. The dark blue dots detail how these causes directly contribute to biodiversity loss.
processes and functions as climate change does or will (Cardinale et al., 2012). Ecosystem services are the benefits that humans derive, either directly or indirectly from the functions of ecosystems (Costanza et al., 1997). The Millennium Ecosystem Assessment (MEA) (2005b) estimates that 60% of global ecosystem services are degraded or are being managed unsustainably. As biodiversity is lost and ecosystems are degraded, the bio-capacity of the planet to support living organisms reduces. As bio-capacity decreases there are diminishing resources available to support a growing human population and increasing collective ecological footprint; for example, the number of available global hectares per person (bio-capacity) has dropped from approximately 3.7 to 1.8 since the 1960s (WWF, 2010).

2. HOW DOES THE BUILT ENVIRONMENT CONTRIBUTE TO BIODIVERSITY LOSS?

The built environment, with its highly altered landscapes and rapid human-caused changes to local ecosystems is accepted as a major driver of biodiversity change (Nielsen et al., 2014). Key anthropogenic drivers of biodiversity change are:

- land-use and land cover change (Seto et al., 2012; Lambin et al., 2001),
- climate change (Barnosky et al., 2012; Gitay et al., 2002),
- nitrogen deposition and acid rain (Rockstrom et al., 2009), and
- the introduction of invasive species to ecosystems (termed ‘biotic’ exchange) (Bellard et al., 2012; Chapin et al., 2000; Sala et al., 2000).

The built environment contributes to each of these drivers (see Figure 1). Possible synergies or reinforcing feedback mechanisms between these and other drivers of biodiversity loss, particularly climate change make predictions of exact effects on future biodiversity difficult to quantify (Cahill et al., 2013). However, consequences are thought to be ‘extremely worrisome’ with worst case scenarios resulting in the sixth mass extinction in Earth’s history (Bellard et al., 2012).

2.1 LAND-USE AND LAND COVER CHANGE

The globally pervasive change in land-use and land cover since the mid-1800s, and particularly since 1950, has added significantly to climate change, soil degradation and loss of ecosystem services as well as loss of biodiversity (Ramalho et al., 2012; Lambin et al., 2001). It is the largest driver of biodiversity change due to loss of available habitat and resulting extinctions (Le Roux et al., 2014; Sala et al., 2000), though this may be surpassed by climate change in the near future (Bellard et al., 2012; Cahill et al., 2013). Cities occupy less than 3% of global available land (McGranahan et al., 2005), but urbanisation does impact on land-use change through important urban-rural linkages and cannot be ignored (Andersson, 2006; Lambin et al., 2001; McGranahan et al., 2005; Pickett et al., 2008). The conversion of wild or agricultural land to urban or suburban use is expanding at a rate approximately twice as fast as urban population increase (Seto et al., 2012; Pickett et al., 2008). By 2030 urban land cover will likely expand by 1.2 million km$^2$, a threefold increase compared to the year 2000 (Seto et al., 2012). Demand for building materials, particularly timber, much of which is unsustainably or illegally obtained, is a driver of change (Pollock, 2009; Rands et al., 2010). Demand for increased food for growing urban populations also results in land beyond city limits being converted to agricultural production, particularly the conversion of land into pasture. For example, the global expansion of croplands since 1850 has converted approximately 6 million km$^2$ of forests and woodlands and 4.7 million km$^2$ of savannahs, grasslands and steppes (Lambin et al., 2001). 40% of the Earth’s land has been converted for agricultural use and much of the remainder of land is networked with roads (Barnosky et al., 2012).

The expansion of urban areas and their satellite settlements, along with the construction of supporting infrastructure, can result in fragmentation and hence degradation of ecosystems (Seto et al., 2012; Brook et al., 2008; Hanski, 2005; Krauss et al., 2010). Fragmentation can result in an ‘extinction debt’ meaning that it can take up to 50 years for the results of the impacts on biodiversity to occur. This means that conventional management strategies of fragmented ecosystems are insufficient to prevent future loss of biodiversity (Krauss et al., 2010). The impact of climate change on biodiversity is thought to be worse in fragmented landscapes (Hanski, 2005), because penetration of predators, invasive species, wind damage, and fire risk is increased. Fragmentation also prevents species migrating in response to introduced threats or climate change. This is because habitat patches become isolated in a matrix of built up impervious areas and roads (Niemelä, 1999). The process of urbanisation also converts large areas of land, destroys habitat, and is usually irreversible (Barnosky et al., 2012; Lambin et al., 2001). Places that experience the most human development are often places of high biological diversity and high ecosystem productivity, such as riparian corridors and coastal land margins (Le Roux et al., 2014; Nielsen et al., 2014). This leads to further significant biodiversity loss (Sala et al., 2000).

2.2 CLIMATE CHANGE

The emission of greenhouse gases (GHG) including carbon dioxide, methane, nitrous oxide, tropospheric ozone and chlorofluorocarbons and their effect on the atmosphere is the leading cause of climate change (Walther et al., 2005; Warren et al., 2013). Estimates of the contribution from cities to global GHG emissions vary from 30% to as high as 80% (de la Rue du Can & Price, 2008; Satterthwaite, 2008; Spiegelhalter & Arch, 2010). This is due to the construction and operation of buildings accounting for high energy consumption and large production of waste (Bulkeley & Betsill, 2005; Ewing et al., 2008). Up to 40% of all energy and material resources are used to construct and operate buildings and up to 40% of total solid waste results from construction and demolition activities (UNEP, 2011). Construction and demolition waste can contribute to climate change either through the emission of GHGs as materials decompose, or due to the release over time of...
fluorinated gases with a high potential for global warming from certain construction- and demolition-related wastes (Bogner et al., 2008). The United Nations Environment Programme (UNEP) (2011) states that: “The global use of natural resource materials increased by over 40% between 1992 and 2005, from about 42 to nearly 60 thousand million tonnes. On a per capita basis, the increase was 27%. ... There has been a major increase in extraction of construction minerals of almost 80%.” (p.16) Building sector carbon emissions including those from energy generation used to power buildings have increased by 2% per annum since 1970, while emissions from commercial buildings have increased by 3% per annum since 2002 (Levine et al., 2007). This is a higher growth rate than that of the global human population, which has varied from approximately 1.8% per annum in 1970 to slightly more than 1% in 2011. This suggests that buildings have become higher energy consumers and/or that building floor area is increasing. High rates of impervious surfaces in urban areas contribute to several ecological issues. In terms of climate change, expanding impervious areas could potentially reduce soil carbon pools by up to 66% (Seto et al., 2012). The design of urban environments also contributes to how private vehicles, most of which are powered by burning fossil fuels are used, leading to further built environment-related GHG emissions (Baur et al., 2014; Ewing & Rong, 2008; Steemers, 2003).

2.3 NITROGEN DEPOSITION AND ACID RAIN

Nitrogen deposition is mostly related to industrial fixation of nitrogen for fertilizer. This has resulted in a doubling of the processes that make nitrogen biologically available (Rockstrom et al., 2009). Major ecological changes in river basins, estuaries and coastal zones have occurred as a consequence of run-off of these nutrients from agricultural and urban areas (Chapin et al., 2000), partly due to urban environments being made up of mostly impervious surfaces (such as roads, footpaths and buildings). Acid rain is caused by certain gases dissolving in atmospheric water to form acids which, falling as rain, can cause deforestation in land ecosystems and severe negative changes in aquatic systems. Although the cause of acid rain can be natural, for example from volcanic eruptions, it is mostly caused by human emissions of oxides of carbon, sulphur and nitrogen. These emissions are caused by industrial processes, the generation of power by fossil fuels (coal in particular) and use of petrol- and diesel-burning vehicles (Mehta, 2010). Bearing in mind that 40% of energy is used in the built environment (UNEP, 2011), and the form and density of urban areas contributes to rates and patterns of per capita energy and vehicle use (Seto et al., 2012; Baur et al., 2014; Steemers, 2003), the urban built environment, therefore, is strongly implicated.

2.4 BIOTIC EXCHANGE

The nature of urban environments and the movement of humans between them tends to increase the prevalence of species exotic to a particular place and hence the existence of invasive species in native ecosystems (Gaston, 2005; Niemelä, 1999). In a recent review of literature, Nielsen et al. (2014) found that in many parts of the world urban parks are made up of approximately half exotic species. The planting of exotic plant species in parks and residential gardens contributes to the release of invasive species into fragmented native ecosystems and often results in their degradation (Nielsen et al., 2014). Areas disturbed by humans provide opportunities for non-native ‘weedy’ species to colonise these areas. The amount of energy and matter (food) available for species also increases towards a city core due to rubbish and the heating of buildings and some ‘urban exploiter’ species such as pigeons, sparrows, starlings, mice, rats and cockroaches thrive in these conditions and compete with native species (McKinney, 2002). Urban areas tend to be warmer through the heat island effect and so become climatically unsuitable for some native species (Niemelä, 1999).

3. THE IMPACTS OF ECO SYSTEM DEGRADATION AND LOSS OF BIODIVERSITY ON THE BUILT ENVIRONMENT

Changes in biodiversity and the on-going degradation of ecosystems will likely have severe and difficult to predict impacts on human society in terms of physical, psychological, and economic wellbeing (MEA, 2005a; Chapin et al., 2000; Rockstrom et al., 2009; TEEB, 2011). Rapid, difficult to predict, and irreversible transitions in ecosystem states can occur when they are forced across critical thresholds (Brook et al., 2013; Barnosky et al., 2012; Cardinale et al., 2012). Because the impacts of ecosystem degradation are numerous in scope at both spatial and temporal scales, this section will only detail broad trends that relate to the built environment. Unlike the impacts of climate change, changes in biodiversity tend not to affect the physical fabric of the built environment directly and are therefore indirect in nature. Indirect impacts will affect the economic, social and environmental context in which the built environment operates.

The results of a comparative analysis of international research examining the main impacts of changes in biodiversity related to the built environment have been summarised in Table 1 (for further details, including methodology, see Pedersen Zari, 2012b). Rapid or non-linear changes caused when ecosystem or biodiversity thresholds are reached will vary greatly from region to region (Chapin et al., 2000). It is important, therefore, to understand the nature and timing of these changes from a local perspective when designing for a specific site. While some of the impacts listed in Table 1 may appear to be less severe than climate change impacts because they are less direct in nature, the overall outcome of continued loss of biodiversity results in a threat to the continuation of human society in its present form (Chapin et al., 2000). This is because humans not only negatively affect biodiversity, but are also affected by the health of ecosystems (made up of biodiversity), because humans are dependent upon ecosystem services for survival (Diaz et al., 2006). Biodiversity loss that results in extinction of specific species is of course irreversible (Chapin et al., 2000).

Recent research indicates that when critical thresholds are passed in ecosystems leading to biodiversity loss and possible collapse of certain ecosystem services, the impacts on humanity could be severe, potentially including widespread social unrest,
evidence suggests that global ecosystems may indeed be approaching a planetary-scale critical transition as a result of human influence (Barnosky et al., 2012). These factors could have correspondingly severe impacts on urban environments not examined in Table 1.

Table 1: Impacts of Changing Biodiversity on the Built Environment

<table>
<thead>
<tr>
<th>Potential indirect biodiversity loss/alteration impacts</th>
<th>Potential consequences for the built environment:</th>
<th>Possible scale of the impact:</th>
</tr>
</thead>
<tbody>
<tr>
<td>More rapid climate change due to biophysical feedbacks of ecosystems and loss of carbon sequestration.</td>
<td>Climate change impacts on the built environment are both direct and indirect.</td>
<td>High</td>
</tr>
<tr>
<td>Reduction in resilience of ecosystems to environmental change.</td>
<td>Increased damage to buildings and infrastructure from storm events, floods, landslides and wildfire.</td>
<td>High</td>
</tr>
<tr>
<td>Increased disease/pest risk to crops, animals and humans. Changes in productivity/timing of crops. Loss of available protein and vitamins from food sources. Loss of soil nitrogen and carbon. Changes in soil fertility.</td>
<td>The built environment may be expected to allow for food growing more effectively. Human work force and inhabitants may be negatively affected and impact indirectly on the viability of the built environment. Building materials such as timber may be affected.</td>
<td>High (potentially positive)</td>
</tr>
<tr>
<td>Changes to precipitation patterns and water availability and quality. Warmer, drier climates. This can occur through increasing replacement of many land types with pasture for example.</td>
<td>Increased cooling loads. Reduction of water availability. Increased cost of water. Increased requirement for buildings to harvest rainwater.</td>
<td>High</td>
</tr>
<tr>
<td>Loss of provision of ecosystem services (such as fuel, structural materials, etc.).</td>
<td>Changes in the viability of some urban environments to support human life. More expensive construction costs. Changes in availability and costs of materials.</td>
<td>High</td>
</tr>
<tr>
<td>Negative impacts on animal, plant and human physical health.</td>
<td>Changes in capabilities to design, construct, and maintain the built environment. User capabilities and expectations of the built environment may change.</td>
<td>High</td>
</tr>
<tr>
<td>Increased social dislocation, poverty and loss of income particularly of indigenous and poor communities.</td>
<td>Increased urban populations through rural migration. Poorer quality of building stock.</td>
<td>Medium</td>
</tr>
<tr>
<td>Increased local and international emigration and immigration.</td>
<td>Changes in expectations of the built environment to accommodate different and possibly increased numbers of users. Changes in population and activity patterns will affect expectations of and viability of parts of the built environment.</td>
<td>Medium</td>
</tr>
<tr>
<td>Changes in global and regional economies.</td>
<td>Shifts in money and resources available for construction. Changes in costs to run/build the built environment.</td>
<td>Medium</td>
</tr>
<tr>
<td>Increase in regulations to protect biodiversity.</td>
<td>Changes in construction methods. Changes in materials available, suitable and desirable for construction. Changes in development zones. Greater skill and knowledge required to design. More vegetation in urban areas. Increased multidisciplinary collaboration. Increased use of the precautionary principle.</td>
<td>Medium</td>
</tr>
<tr>
<td>Reduction in air quality, increase in acid rain.</td>
<td>Damage to building materials and infrastructure.</td>
<td>Medium</td>
</tr>
<tr>
<td>Decline in human mental health.</td>
<td>Changes to workforce available to build and maintain the built environment. Desire to have more vegetation in urban areas.</td>
<td>Medium</td>
</tr>
<tr>
<td>Loss of ‘option value’, through increased extinctions or biodiversity loss.</td>
<td>Less ability to develop responses to future changes that could affect the built environment.</td>
<td>Medium</td>
</tr>
</tbody>
</table>

1 Option value is ‘the value of attaining more knowledge about species and their contribution to human wellbeing in order to make informed decisions in the future’ Chapin et al. (2000: 240).
4. RESPONSES TO ECOSYSTEM DEGRADATION IN THE BUILT ENVIRONMENT

Although urban areas cannot alone solve all of the identified causes of biodiversity loss, the way people build and inhabit the built environment contributes to the causes of biodiversity loss and may also potentially begin to address these problems (Nielsen et al., 2014). The urban built environment is the main site of human economic, social and cultural life in terms of both magnitude and significance. More than half of all humans now live in urban built environments, a figure predicted to rise to 60% by 2030 (Eigenbrod et al., 2011). It is also where nations invest large amounts of money and resources in terms of energy and materials (IPCC, 2007a). It is important then that the built environment contributes to mitigating the causes of biodiversity loss but also is able to adapt to its impacts.

Typical responses to addressing the loss of biodiversity in a built environment context (Figure 2) are:

• protection or conservation of remnant ecosystems through covenants or nature reserves,
• provision of connections between remnant habitats to reduce fragmentation,
• restoration of degraded ecosystems, and
• management of urban vegetation and/or structure to increase biodiversity.

Actions that target education, policy changes, and economic penalties or rewards can also result in biodiversity benefits but are considered to be outside the scope of this paper.

4.1 PROTECTION OR CONSERVATION OF REMNANT ECO-SYSTEMS

The global network of protected areas has grown by approximately 2.5% per annum between 1992 and 2009 in total area, and 1.4% per annum in number of actual sites (an overall increase of 42%), but many sites may be poorly managed (Rands et al., 2010; UNEP, 2011). WWF (2010) state that: “In 2009, there were over 133 000 nationally designated protected areas covering a total of nearly 19 million square kilometres of land and sea, or 12.9 per cent of the Earth’s land area and 6.3 percent of the Earth’s territorial seas” (p.85). Habitat preservation is thought to be the cheapest and most effective long-term way to reduce biodiversity loss (McKinney, 2002) and store carbon (Gitay et al., 2002), and will likely become increasingly important in the near future (Ramalho & Hobbs 2012; Le Roux et al. 2014). Native species richness increases with the area of habitat available, particularly for plants, birds and mammals (McKinney, 2002). The built environment itself cannot mimic non-human integrated ecosystems, but built environment policy and regulations could contribute to the protection of biodiversity through effective land-use management. Strategies include:

• Defining zones that are inappropriate to build in, by virtue of being an existing or recovering native ecosystems. This may involve introducing ecological knowledge into urban planning practices to increase understanding of the composition and patterns of urban biodiversity, for example through biotope mapping (Mathieu et al., 2007; Niemelä, 1999; Pickett et al., 2008).
• Maintaining and adding to existing protected ecosystems in or adjacent to urban places (Le Roux et al., 2014; Ramalho & Hobbs 2012; McKinney, 2002).
• Preventing road building or other activities that lead to fragmentation within protected areas (Hanski, 2005).
• Defining set boundaries for urban sprawl through the use of ‘green belts’, and preservation of pre-development biodiversity in greenfield development (Niemelä,
Advocating that increasing density in urban environments will mitigate the causes of declines in ecosystem health (and climate change) is controversial (Tratalos et al., 2007). Preventing unbounded urban sprawl is up to three times more beneficial in terms of limiting the loss of stored carbon as well as preventing conversion of agriculturally productive land (Eigenbrod et al., 2011). Densification may also: increase stormwater flows and run-off caused by increased impermeability; increase the number of people living in potential flood zones (Eigenbrod et al., 2011); increase air pollution and urban noise (Steemers, 2003); increase maximum urban temperatures (Tratalos et al., 2007); result in conversion of urban green and garden space resulting in loss of biodiversity, carbon sequestration potential, and ecosystem service provision (Le Roux et al., 2014; Bastian et al., 2012; Loram et al., 2007); and compete in some cases with ecosystem conservation efforts (Niemelä, 1999). Therefore it should not be assumed that a policy of increasing density in urban environments is necessarily the best way forward, particularly if densification will exacerbate other environmental issues (Seto et al., 2012; Steemers, 2003).

The built environment also has a part to play in mitigating the causes of biodiversity loss aside from land-use change through: avoiding pollution of ecosystems; avoiding overharvesting (through unsustainable forestry, and collection of firewood); careful materials selection (for example, purchasing building materials with appropriate certification labels such as the Forest Stewardship Council’s FSC sustainable timber mark); reducing fire risk; and, perhaps most importantly, reducing GHG emissions due to the negative impact climate change will have on ecosystems (Bellard et al., 2012). These interacting causes of change should be planned for to avoid negative cascading effects of multiple interacting drivers (Brook et al., 2008; McKinney, 2002).

4.2 PROVISION OF CONNECTIONS BETWEEN REMNANT HABITATS TO REDUCE FRAGMENTATION

Maintaining or creating connectivity (in terms of both structure and function) between urban green areas can relate to the creation of ‘wildlife corridors’ or ‘greenways’. This facilitates the movement of species between remnant patches of habitat, reduces the effects of fragmentation, potentially enables seasonal migrations to continue, and may enable some species to adapt better to climate change (Dawson et al., 2011; Heller & Zavaleta, 2009). The success of wildlife corridors or greenways is highly dependent on site-specific conditions including coordination between multiple authorities, the type of species using the corridor, and the presence of existing remnant ecosystems. Their use can be controversial, and a detailed analysis should be undertaken for each proposed corridor to determine benefits or disadvantages of such proposals (Sefo et al., 2012; Andersson, 2006).

Connectivity routes are typically created through providing a piece of suitable land that physically connects one piece of habitat to another. Other architectural design concepts that could potentially contribute to increasing connectivity include green roof design (Lundholm, 2006), green infrastructure design (Gill et al., 2007), and potentially some forms of urban agriculture. Corridors and greenways should be managed for the benefit of native (rather than exotic) species and should not become substitutes for the protection of large intact nature reserves within urban, suburban, or periurban settings (Niemelä, 1999).

4.3 RESTORATION OF DEGRADED ECOSYSTEMS

The restoration of degraded ecosystems can add to biodiversity health and therefore increase the health of ecosystem services. Restoration of degraded urban ecosystems often takes the form of citizen- or council-initiated clean-ups of streams, beaches and polluted sites, replanting of previously removed vegetation, and pest and weed eradication schemes on degraded land. It may also include improving land tenure, as well as sustainable land, water, and agriculture management.

A growing body of research and design strategies, termed here ‘ecological design’, have as their basis a motivation to restore biodiversity or the health of ecosystems through various built environment design methods. Regenerative design is one aspect of this, and is discussed below. Other examples of design that could potentially contribute to the restoration of biodiversity are: ecologically designed urban landscapes and ‘eco-revelatory design’, where ecological processes are made visible as a way to educate people about them (Eisenstein, 2001); ‘building ecology’, with an emphasis on education of building professionals about relationships between the built environment and ecosystems and a system approach to design (Graham, 2003); ‘biophilic design’, based on the idea that humans have an innate affinity with the living world that can be reflected in design (Kellert et al., 2008); ‘construction ecology’, where ecosystems provide energy and material flows in urban areas and humans provide nutrients to ecosystems (Kibert et al., 2002); ‘bioregionalism’, with an integrated understanding of deep ecology concepts (Lombard Ortíz, 2003); the planned integration of human social and ecological processes for the mutual benefit of both (Van Der Ryn & Cowan, 2007); ‘cradle to cradle’ design, where materials are used in connected cycles, thus eliminating waste and pollution (McDonough & Braungart, 2002); and using ecological processes to remediate pollution or degradation of ecosystems (Todd & Todd, 1993).
4.4 MANAGEMENT OF URBAN VEGETATION AND STRUCTURE TO INCREASE NATIVE BIODIVERSITY

Urban environments typically include parks, playgrounds, vacant lots, roadsides, street plantings, residential backyards, community and botanical gardens and sports grounds, and tend to have relatively high levels of biodiversity (Nielsen et al., 2014). Managing the vegetation within these open or green spaces to assist native plants and fauna may make a significant contribution to biodiversity conservation or restoration (McKinney, 2002). It may also contribute to connectivity strategies.

The trend in many industrialized nations is towards increasing amounts of vegetation in urban areas (McGranahan et al., 2005), though this vegetation tends to be fragmented (Seto et al., 2012). Private ownership of green spaces (such as residential gardens) may mean control is de-centralised, rendering management for the benefit of biodiversity more difficult (Goddard et al., 2010). At the individual scale of a building, it is important that landscaping is done with sensitivity to increasing native biodiversity or to preserving or enhancing local ecosystem services. Private land owners may be able to contribute to increasing avian, insect and plant biodiversity within the city through careful choice of plantings.

Additional habitat (not necessarily similar to that which existed before development) could be provided by the addition of infrastructure such as nesting boxes, water sources, high ledges (Goddard et al., 2010), ecologically engineered walls (Francis, 2011) and seawalls (Chapman & Blockley, 2009), and by assisted dispersal of species. Some researchers (Lundholm & Richardson, 2010; Rosenzweig, 2003; Wolch et al., 1995) point out that because it may be difficult or impossible to recreate habitats that previously existed on certain sites, effort should also be made to provide habitat for native species that may be more analogous to urban environments (for example, walls and quarries resemble rocky habitats). This could be a way to increase the resilience of certain species as global climate change continues. Lundholm & Richardson (2010) point out that “anthropogenic ecosystems are largely distinct in structure and function from the natural ecosystems they replaced because of alterations to resource availability, stress intensity, disturbance, and changes in the spatial arrangement of ecosystem components” (p.967). More discussion of these ideas can be found in the work of proponents of ‘ecosystem analogue’ ideas and ‘reconciliation ecology’ (Lundholm & Richardson, 2010; Rosenzweig, 2003).

Preserving rare species within urban environments through active management can also contribute to the protection of biodiversity (Gitay et al., 2002; McKinney, 2002). There is evidence that rare species occur in some urban environments at surprisingly high rates, and can be found most commonly in parks, cemeteries, by railway tracks, or in vegetated areas under power lines and in other public rights of way that are protected from development (Niemelä, 1999). Although it is not clear if this applies to all climates or types of urban areas, this highlights the importance of identifying which species exist in a particular place before green or brownfield development is approved.

Urban habitats are typically at early successional stages because regular disturbances occur, such as mowing, trimming, and pruning (McGranahan et al., 2005). Natural succession increases species diversity, and there is some evidence that it increases native diversity and reduces non-native species in some locations (McKinney, 2002). This means that older residential neighbourhoods may exhibit greater biodiversity than newer ones (Tratalos et al., 2007), although this may not be the case with urban parks (Nielsen et al., 2014). ‘Benign neglect’ may therefore be an option for maintaining species diversity and richness of habitat in some urban settings, particularly if older trees are protected and younger trees are able to mature (Nielsen et al., 2014; McKinney, 2002). This entails leaving some areas unmanaged, lightly managing others, and actively intervening in still others. The variation of management strategies may produce a more diverse urban ecology with areas in different states of succession and rich in habitat niches (Niemelä, 1999). Various policy mechanisms, such as zoning, development right transfers, and environmental impact statements have been used to increase habitat in urban areas with varied levels of success (Wolch et al., 1995).

5. THE RELATIONSHIP BETWEEN RESPONSES TO CLIMATE CHANGE AND BIODIVERSITY HEALTH IN A BUILT ENVIRONMENT CONTEXT

Responses to climate change and the loss of biodiversity vary. It is important that responses are complementary rather than antagonistic in addressing these two issues. Site selection and management practices are crucial to determining whether activities related to climate mitigation, such as land-use change, reforestation or conservation, and renewable energy generation, will affect biodiversity positively or negatively (Gitay et al., 2002). It is important that responses take into account interactions between drivers of change over long time periods, to ensure that actions are beneficial in both reducing climate change and maintaining biodiversity. Management of single drivers is unlikely to be adequate (Brook et al., 2008), while the effectiveness of strategies can be enhanced when they are part of broader approaches to address other impacts of global change (Gitay et al., 2002). For example, increases in the production of biofuel can be positive within a climate change mitigation agenda because biofuel can replace fossil fuels in some instances and therefore reduce GHG emissions, but from a biodiversity point of view, increased crop production of a variety of oils and fuels has meant the destruction of existing ecosystems to provide land for the crops (UNEP, 2011). This has had severe negative biodiversity implications for certain places in Asia, for example (Rands et al., 2010). In contrast, protecting or regenerating native forest on degraded

1 Following disturbance, ecosystems go through various stages of development as they regenerate. These can be termed successional stages.
Human activities and behaviours have impacted negatively on the climate and on ecosystems (represented by the red arrows). Changes in climate are known to be largely anthropogenic in origin, and stem from many different kinds of human activities (Walther et al., 2005). This means direct and indirect impacts of climate change on human societies are occurring (represented by blue arrow right side). The degradation of ecosystems and loss of biodiversity are also caused by numerous human activities. This results in the loss of ecosystem services, in terms of both quality and quantity (Díaz et al., 2006) (represented by blue arrow on left). The feedback caused by human induced drivers of change between the climate and ecosystems amplifies in many instances the speed and scale of both climate change and biodiversity loss (illustrated by blue arrows connecting climate and ecosystems) creating a self-reinforcing feedback loop (Rockstrom et al., 2009; Gitay et al., 2002).

Green arrows represent how regenerative design could contribute to reducing anthropogenic causes of climate change and decline of ecosystem health. The impacts of climate change and significant loss of biodiversity are occurring and will occur despite any actions humans take collectively now (Gitay et al., 2002), so blue arrows representing this remain on figure 4. Red arrows illustrate a dampening or possible reversal of the self-reinforcing feedback loop between climate change and decline of ecosystem health and biodiversity.
land to provide carbon sinks is likely to have biodiversity benefits if these are considered at the planning stage. However, the creation of carbon sinks does not address the use of fossil fuels, or provide an alternative to their use.

6. REGENERATIVE DESIGN: RESPONDING TO BIODIVERSITY LOSS AND CLIMATE CHANGE SIMULTANEOUSLY

Because there is a synergistic relationship between the climate and ecosystems (Brook et al., 2013; Norberg et al., 2012; Araújo & Rahbek, 2006), additional strategies to address the causes and impacts of climate change may be found by reducing the loss of biodiversity and working to restore the health of ecosystems (Figure 3). This would at the same time restore or create ecosystem services and add to resilience (Dawson et al., 2011; Chapin et al., 2000; Rands et al., 2010).

Many current biodiversity loss and climate change mitigation and adaptation strategies can be described as ‘sustainable’. While this is an improvement on design that does not consider environmental impacts at all, ‘sustainable’ design nevertheless tends to result in negative environmental impact (Reed, 2007). Sustainable design seeks to minimise pollution rather than achieving clean air, soil and water; it minimises energy use, rather than using energy from non-damaging renewable sources; it minimises waste rather than eliminating it altogether by creating positive cycles of resource use; and so on. Within this paradigm, the built environment continues to degrade the ecosystems and climate humans are dependent upon for well-being, wealth, and basic survival. Currently, most urban environments are built in such a way that the outcome is detrimental to climate, ecosystems, and ultimately therefore to people, rather than nearing even approximate ‘sustainability’ (Newman, 2006).

Given the urgency of the changes needed, and the severe outcome for humans should efforts not go far enough to reduce damage, the built environment may need to go beyond efforts to minimise negative environmental outcomes, setting a new goal of increased ecological health (Reed, 2007). This implies that the built environment should contribute more than it consumes to ecosystems while simultaneously remediating past and current environmental damage where possible. Development that enables ecosystems to recover the health they had before humans disturbed them, and could return to being self-sustaining, can be termed ‘regenerative’ (Cole, 2012; du Plessis, 2012). Crucial to regenerative design is a systems-based approach, in which buildings are not considered as individual objects, but are thought of as nodes in a system, much as organisms form part of an ecosystem. The intention of this is that it may enable complex and mutually beneficial interactions between the built environment, the living world, and human inhabitants. Regenerative design is holistic in nature. The social or community aspects of a project are enmeshed with ecological health in terms of both physical and psychological well-being (du Plessis, 2012).

Replacing conventional design strategies with regenerative design strategies in the built environment could contribute to reducing human-caused biodiversity loss (Figure 4). At the same time, generation of additional ecosystem services may be provided either directly by the built environment, or by integrating it effectively with naturally occurring ecosystem processes (Pedersen Zari, 2012a). One aspect of regenerative design is a focus on increasing biomass and thus potentially increasing the storage and/or sequestration of carbon. This, as well as ceasing the use of GHG-emitting energy sources, are two ways in which a regenerative development paradigm would contribute to reducing the causes of climate change, and hence also its impacts, particularly over the long term. Increasing the provision of habitat may increase the health of ecosystems and also increase the resilience of ecosystems. This could also potentially increase the resilience of human urban environments if they were integrated into ecosystems as an adaptation response to climate change (Chapin et al., 2000; Gitay et al., 2002). An additional benefit of a regenerative design strategy is that regeneration of ecosystems may reduce some of the causes and ameliorate certain impacts of climate change and therefore loss of biodiversity, dampening the positive feedback loop between climate change and biodiversity described earlier (Figure 3). This would likely have a non-linear effect, with each tenth of a degree in temperature rise avoided resulting in saving an increasing number of species (Bellard et al., 2012).

The impacts of climate change and significant loss of biodiversity are occurring and will occur despite any actions humans take collectively now (Norberg et al., 2012; IPCC, 2007b: 12, Rockstrom et al., 2009, Chapin et al., 2000, Gitay et al., 2002), so arrows representing this remain on Figure 4. This inevitable change is due to historic and current emissions of GHGs and disruption of ecosystems and species extinctions that have already occurred (Dawson et al., 2011).

New building projects do provide substantial opportunities for initiating and demonstrating change, but most buildings that will still be occupied when the effects of climate change and biodiversity loss become more acute have already been built in many urban centres. Because it is not possible to replace the entire built environment, individual or small scale regenerative developments may have to reduce, counter and reverse not only their own negative impacts but also those of existing neighbouring buildings in a given urban environment. The feasibility of this, a method for implementing regenerative design based on ecosystem service analysis, and a case study devising regenerative design goals in an existing city have been examined and proposed in earlier research (Pedersen Zari, 2012a, 2012b).

Within a regenerative design approach, ecosystem services analysis is the comparison of the ecosystem services provided by a city or development to those provided by a healthy ecosystem prior to development. Such an analysis could provide tangible and measurable regenerative goal metrics based on ecological reality rather than human-defined goals for sustainability (Pedersen Zari, 2012a). So far, ecosystems are the best known example of systems that are able to create
conditions conducive to ongoing life, and that are energy and materials effective. They operate within the same climate and laws of physics as urban areas, so may prove to be a suitable model for what urban environments should aim for in terms of optimal environmental performance. Testing the application of this concept to a built environment context (see: Pedersen Zari, 2012b, for details and methodology) resulted in the following seven services, or bundles or services, being identified as appropriate for inclusion in an ecosystem services analysis methodology:

1. Habitat provision (including genetic information, biological control, fixation of solar energy, and species maintenance);
2. Nutrient cycling (including decomposition, soil building, and raw materials);
3. Purification;
4. Climate regulation;
5. Provision of fuel / energy for human consumption;
6. Provision of fresh water; and
7. Provision of food (including provision of biochemicals).

Thus, in a similar way to the functioning of an ecosystem, an urban environment (and individual buildings within it) could be designed with a deliberate focus on generating a system that provides habitat for species suitable for co-inhabitation with humans in the urban built environment; contributes to soil formation and fertility through careful cycling of biodegradable wastes and recycling of non-biodegradable wastes; purifies air, water and soil; contributes to regulating climate through mitigating GHG emissions and the heat island effect, and by sequestering carbon; produces renewable energy; collects and distributes fresh water; and produces human food. The methods used to create the list of ecosystem services that could be used to conduct ecosystem services analysis in a built environment context produced a more manageable set of ecosystem services for a design context, while still capturing a wide range of ecological considerations. It should be remembered that this is not a ranking of the ecological importance of the ecosystem services alone, but a consideration of their suitability for integration into the built environment. Such a list should be revisited as knowledge gaps are filled in the field of ecology and the understanding of ecosystem services.

Another outcome of the research was that if regenerative developments within existing urban settings could start to provide ecosystem services beyond their own needs or boundaries, the built environment causes of ecological decline and climate change may in part be mitigated. Clearly, retrofitting an existing city to become a completely regenerative urban environment would require wide-scale and rapid changes in dominant economic systems and human behaviour; however, incorporating an understanding of ecosystem services into regenerative design may be a promising approach for a longer-term response to adapting to climate change, mitigating the causes of it, and addressing the decline of ecosystem health and biodiversity in the built environment. This approach merits further research and testing in built form.

7. CONCLUSION

Addressing the decline in ecosystem health and loss of biodiversity in terms of both scale and scope needs many solutions to fit the vast variety of political, economic, cultural, climatic, and ecological conditions within which humans dwell. Much like climate change, it is an urgent task of great magnitude with uncertain outcome. Strategies that employ the medium of the built environment to effect change could be one such set of solutions. If the dominant economic philosophies and structures of human society and their resulting behaviours do not or cannot change in the short to medium term, it is doubtful that new or existing forms of design thinking and practice, or new technologies will alone be able to create significant change, before humanity is severely affected by the degradation of ecosystems and changes in climate (Mitchell, 2012; Turner, 2008).

Because of the great variation of impacts in different locations, responses to biodiversity loss should be tailored to specific urban environments. Responses to climate change and to biodiversity issues also need to be considered together so that actions taken are beneficial for both climate and ecosystems, rather than antagonistic. Regenerative design could be investigated further for its ability to enable the built environment to address climate change and biodiversity loss. A shift from a built environment that is degenerating ecosystems to one that regenerates capacity for ecosystems to thrive, will not be a gradual process of improvements, but will require fundamental rethinking of architectural and urban design.

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