POLICY PERSPECTIVE

Biodiversity Sensitive Urban Design

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Abstract

Cities are increasingly considered important places for biodiversity conservation because they can harbor threatened species and because conservation in cities represents an opportunity to reconnect people with nature and the range of health and well-being benefits it provides. However, urbanization can be catastrophic for native species, and is a well-known threat to biodiversity worldwide. Urbanization impacts can be mitigated by urban design and development improvements, but take-up of these practices has been slow. There is an urgent need to incorporate existing ecological knowledge into a framework that can be used by planners and developers to ensure that biodiversity conservation is considered in decision-making processes. Here, we distill the urban biodiversity literature into five principles for biodiversity sensitive urban design (BSUD), ranging from creating habitat and promoting dispersal to facilitating community stewardship. We then present a framework for implementing BSUD aimed at delivering onsite benefits to biodiversity, and that is applicable across a range of urban development types and densities. We illustrate the application of the BSUD framework in two case studies focusing on the: (1) protection of an endangered vegetation remnant in a new low-density subdivision; and (2) persistence of an endangered reptile in an established suburban environment.

Introduction

Cities are increasingly recognized as important places for biodiversity conservation, and can harbor a diversity of plant and animal species, including threatened species (Ives *et al*. 2016). They are also important places for conservation from a human perspective. Exposure to nature in cities delivers a remarkable range of health and well-being benefits, including stress reduction, reduced mortality, and improved cognitive development in children (Shanahan *et al*. 2015). Intriguingly, biodiverse green spaces may deliver greater benefits than less diverse spaces (Fuller *et al*. 2007; Pett *et al*. 2016). Biodiversity conservation in cities therefore presents a unique opportunity to reconnect urban residents with nature and its associated benefits.

However, urbanization has myriad impacts on biodiversity, including habitat loss and fragmentation, changes to resource availability, introduction of exotic species, alteration of local climates via the urban heat island,

modification of natural disturbance regimes, and increased levels of chemical, light and noise pollution (Grimm *et al*. 2008). These changes lead to reduced species and genetic diversity, biotic homogenization (McKinney 2006), and loss of ecological function and ecosystem services (Radford & James 2013). Numerous emerging threats, such as those associated with the uptake of LED lighting and energy-efficient (but cavity-free) homes, are likely to have further impacts (Stanley *et al*. 2015). These impacts are long-lasting with little option for reversal, making urbanization one of the greatest drivers of biodiversity loss (McKinney 2006).

Fortunately, some of the negative impacts of urbanization can be mitigated by improvements to the design and construction of new developments, or through retrofitting existing development (Figure 1). Numerous examples of urban design with positive biodiversity outcomes exist (e.g., Hostetler 2012; Beninde *et al*. 2015; Ikin *et al*. 2015, and Table S1 online). However, uptake has been slow when compared to other environmentally

Figure 1 The biodiversity impacts of urbanization can be mitigated by sensitive urban design. (A): Residential development across the road from a protected native grassland remnant in northern Melbourne, Australia. This residential property is devoid of vegetation (save for the lawn on the nature strip), providing little habitat or resources for native species that live in the grassland across the road. Compare this to image (B) (also in Melbourne), where the nature strip has been planted with a variety of native species, including trees, shrubs and grasses. The structural diversity creates a mosaic of habitat for a range of species. (C): The roof and walls of the Jerusalem Bird Observatory have been designed to provide habitat for birds and bats. (D): The biodiverse roof at The University of Melbourne provides a diverse range of habitats, including hollow logs, grassland, and an ephemeral stream. Photo credits. A, B: Georgia Garrard; C: Architecture–WEINSTEIN VAADIA ARCHITECTS, Photography–Amir Balaban; D: Nick Williams.

focused design protocols. In the absence of a practical framework for incorporating existing urban ecological knowledge into urban design and development, planners and developers have little guidance about which design elements to implement, or how to balance biodiversity with other objectives. There is now an urgent need for an evidential urban design protocol that links urban design to biodiversity outcomes.

We propose a framework for incorporating ecological knowledge into urban planning, design and development to achieve onsite biodiversity benefits. This necessitates a fundamental shift in thinking from current practice, where biodiversity losses are "offset" somewhere else. Biodiversity offsetting delivers questionable ecological outcomes because retained patches face ongoing threats from the surrounding environment (Driscoll *et al.* 2013), and the offset is unlikely to ever adequately compensate for the losses incurred (Bekessy *et al.* 2010). Furthermore, offsetting ignores the place-based value of nature, and results in an unmitigated loss of nature in the places where urban residents live, work, and play.

In this Perspective, we outline five principles for biodiversity sensitive urban design (BSUD), and describe a framework for incorporating BSUD into urban development decision-making. Using two case studies, we demonstrate the application of BSUD to greenfield and existing urban environments.

Figure 2 A framework for implementing biodiversity sensitive urban design.

A framework for BSUD

To achieve onsite biodiversity benefits, BSUD must mitigate the detrimental impacts of urbanization, while encouraging community stewardship of biodiversity by facilitating positive human–nature interactions. We have distilled relevant ecological knowledge for addressing the impacts of urbanization into five BSUD principles:

(1) *Maintain and introduce habitat*. New developments can be planned to avoid habitat loss by prioritizing development in areas of low ecological value (Bekessy *et al.* 2012). Retaining and protecting existing vegetation during the development process can also be beneficial for biodiversity (Hostetler 2012; Ikin *et al.* 2015). Habitat can be enhanced or created in existing urban areas by using native plant species and increasing vegetation complexity (Ikin *et al.* 2015; Threlfall *et al.* 2016), adding green infrastructure (Williams *et al.* 2014) or incorporating critical resources and habitat analogues, such as habitat walls (Figure 1C; Lundholm & Richardson 2010). Residential gardens can be significant habitat, so resident-led wildlife gardening programs can make a valuable contribution to biodiversity (Goddard *et al.* 2010).

(2) *Facilitate dispersal*. Dispersal can be facilitated by adding animal movement infrastructure (Taylor & Goldingay 2012), or establishing habitat connectivity corridors through private and public land (Goddard *et al.* 2010). Care should be taken to avoid inadvertently facilitating the spread of invasive weeds and pests.

(3) *Minimize threats and anthropogenic disturbances*. The impact of weeds and exotic predators can be reduced by landscaping with indigenous plants and establishing pet containment programs (Ikin *et al.* 2015). Increased runoff and nutrient loads can be mitigated by vegetated swales and rain gardens, which also deliver biodiversity benefits. The impact of noise and light pollution can be mitigated by sound barriers (although take care that this does not affect dispersal), temporary road closures and dimming or reconfiguring street lights (Gaston *et al.* 2012).

(4) *Facilitate natural ecological processes*. The disruptive effects of urbanization on natural cycles, ecological processes and disturbance regimes (Grimm *et al.* 2008) can be mitigated by providing adequate resources for target species, protecting and enhancing pollinator habitat, and planning to safely enable natural disturbance events such as fire and flooding.

(5) *Improve potential for positive human–nature interactions.*
Cities are human environments and public engagement is key to successful conservation (Cooper *et al.* 2007). Urban design can help facilitate local stewardship of biodiversity by providing "cues to care" (Nassauer 1995), creating opportunities for positive interactions with nature, and addressing conflicts between biodiversity and safety objectives (Ikin *et al.* 2015) or potential ecosystem disservices.

A key challenge for BSUD is providing a framework that is flexible enough to achieve biodiversity and urban development objectives, which are often competing. In this section, we provide some guidance for the implementation of BSUD, drawing on objectives-based decision-making processes (Keeney 1994; Figure 2).

Using this approach, the user first documents existing ecological values, and identifies biodiversity objectives for their site, considering both site and landscape contexts. Examples of biodiversity objectives include increasing the likelihood that threatened species will persist onsite or reintroducing viable populations of native species that are locally extinct. At this stage, development objectives for the site should also be identified, including dwelling targets, infrastructure requirements, and other environmental objectives (e.g., energy consumption or water quality standards). Next, potential BSUD actions are identified, based on the five principles discussed above, and assessed for their capacity to meet all specified objectives. Because it is driven by objectives, and not existing approaches, this process encourages creativity in the identification of potential actions (Keeney 1994), thereby facilitating innovation. Furthermore, because individual BSUD actions are evaluated for their potential to meet ecological and other objectives, this process provides a mechanism for users, including developers and planners, to resolve trade-offs between competing objectives.

To assess the capacity for BSUD to meet biodiversity objectives, those objectives must be measurable. Numerous metrics have been used to assess the impact of urban form on biodiversity, including vegetation cover and proportions of native and non-native species (Lenth *et al.* 2006). These measures are simple to obtain, but are proxies for the amount of "nature" in an area and don't directly measure biodiversity outcomes. We propose viability, or the probability that target species and ecosystems can persist onsite once development occurs, as a more direct and meaningful measure. This can be assessed using multiple methods, including, in increasing order of complexity:

(1) *Literature review* – existing information may be sufficient to develop conceptual models capable of predicting whether an individual action will improve or worsen persistence probability (see Mata *et al.* 2016);

(2) *Expert elicitation* – where insufficient or lacking, information can be elicited from experts (*Burgman et al.* 2011), as demonstrated in Case Study 1; and

(3) *Population viability analysis* (*PVA*) – PVAs provide the most transparent framework for exploring how species persistence is linked to urban design, but require detailed data and can be troubled by uncertainty in estimates of the absolute risk of decline. Nevertheless, they are reliable tools for assessing relative risk (McCarthy *et al.* 2003), and can be legitimately used to compare alternative BSUD actions, as demonstrated in Case Study 2 (see Wintle *et al.* [2005] for another example of PVA to assess scenarios).

Although challenging, this step enables users to choose the action or actions that best meet biodiversity and other objectives in the final step of the framework. Trade-offs may be necessary; for example, if there are conflicts between biodiversity and other environmental or development objectives, if biodiversity leads to disservices (Lyytimäki & Sipilä 2009) or if an action benefits one species, but is detrimental to another. Tools are available to assist with trade-offs (Joseph *et al.* 2009; Bekessy *et al.* 2012), however, transparent trade-offs are only possible where the biodiversity benefits of individual BSUD actions can be compared using a common metric.

Case Study 1. BSUD to protect native grasslands in greenfield development

We consider the hypothetical (but realistic) development of a 35 ha site in an urban fringe setting typical of those in northern and western Melbourne, Australia. The site, historically grazed by horses, is bounded on two sides by residential and industrial land uses, and by undeveloped agricultural land interspersed with native grassland remnants on its remaining boundaries.

Biodiversity values

A 5 ha remnant patch of critically endangered grassland exists within the site along one boundary. It is of significant ecological value and legislation will require that it is retained and protected. Because the remnant partially adjoins other remnant grasslands in adjacent properties, it additionally makes a contribution to landscape connectivity.

Biodiversity objectives

The primary ecological objective is to improve the viability of the native grassland remnant. The metric used

Table 1 Potential BSUD actions to enhance native grassland viability in low-density greenfield development

Development Phase		BSUD Action	Description
	DESIGN	Appropriate adjacencies	Housing, infrastructure not immediately adjacent to grasslands to reduce conflict with management.
		Effective buffers	Buffers should be allocated OUTSIDE the grassland, be of sufficient width and resistant to weed invasion. Buffers graded away from grassland to minimise run-off and pollution.
		Water sensitive urban design	Employ water sensitive urban design to reduce impact of abiotic hydrological and temperature changes
		Fire-resistant construction	Use fire-retardant construction for housing & infrastructure on the leeward boundary of the grassland.
		Biodiversity sensitive public landscaping	Indigenous plants with low nutrient and water requirements used in local public open spaces.
	CONSTRUCTION	Early protection	No disturbance of grassland remnant during construction. Grassland remnant is protected by appropriate fencing and buffers early in the construction process.
		Clean construction	Sterilisation of vehicles and equipment, and appropriate selection of materials to minimised introductions of weeds, nutrients and other pollutants.
		Appropriate management	Appropriate management of weeds and biomass during the period between land acquisition and the commencement of development activities.
	INHABITATION	Biodiversity sensitive private landscaping	Indigenous plants used in private gardens. Residents encouraged not to plant problematic weeds or use fertilisers.
		Provide "cues to care"	Signage, fencing, trails and viewing platforms used to encourage low-impact use and enjoyment of the grassland. Mixed-use areas should be located close to, but separate from, the grassland.
		Community education	The local community is engaged early, and targeted education programs used to alleviate any potential conflict and misunderstanding regarding the ongoing management of the grassland.
		Facilitate active stewardship	Protocols put in place to ensure a sense of community ownership and stewardship of the grassland.

to measure viability is the probability that the grassland persists in the same or better condition for 25 years.

Development objectives

The site is to be developed as a typical low-density residential greenfield development, and will be subject to minimum housing densities and green space provisions specified by local planning policy.

BSUD Actions

Potential BSUD actions were identified in the design, construction and inhabitation phases of development, and primarily address key threats to native grassland viability associated with disruption to fire disturbance regimes, introduction of invasive weeds and changes to abiotic conditions (Table 1).

Assessing BSUD

Estimates of the overall contribution of BSUD and partial contribution of individual BSUD actions to the grassland persistence were elicited in a workshop with five grassland experts, using a modified Delphi technique (Burgman *et al.* 2011). The elicitation process and expanded results are detailed in the supplementary material.

While there was variation between experts, all experts agreed that, if the grassland was in good condition, BSUD would contribute to a 0.31 increase in the probability of the grassland persisting without deteriorating when compared to a non-BSUD development (Figure 3). The majority of this increase was attributable to BSUD actions undertaken to protect and manage the grassland during the construction phase of development. This effect was likely to be smaller for a grassland initially in poor condition.

(Note that urban development contributed to a marginal increase in the persistence of the native grassland, even without BSUD. This reflects expert pessimism about the capacity for grassland condition to be maintained in the absence of any weed or biomass management.)

Decide

All BSUD actions were considered to contribute to an improvement in the viability of the grassland remnant, so the final decision about which actions to take requires a trade-off between the biodiversity benefits provided and the costs of implementation (which may include financial costs and conflicts with other social and environmental objectives). It is impossible to compensate for losses associated during construction via any other means, so protection and management during this stage should be
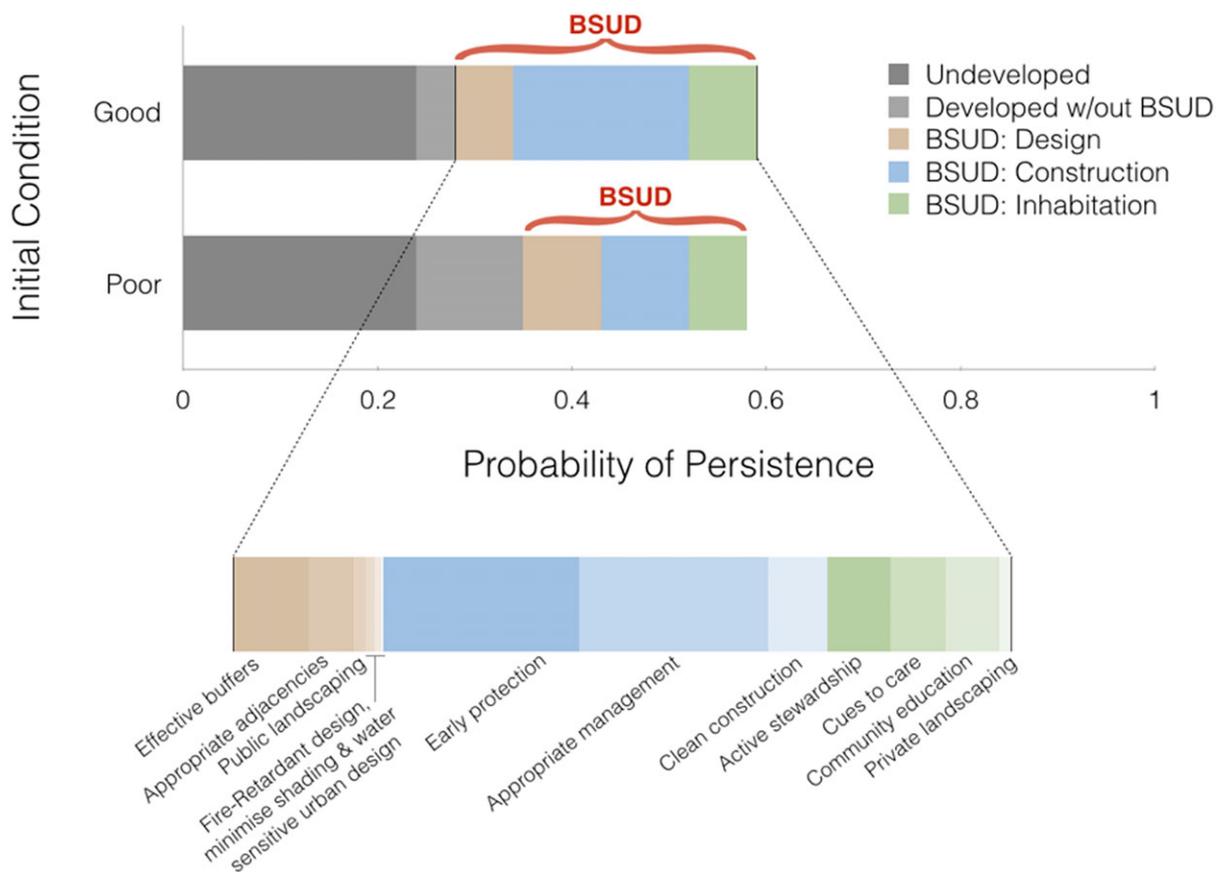
Figure 3 Expert elicitation results, showing the contribution of BSUD to the probability of persistence of a remnant native grassland in low-density greenfield urban development. Results are presented for grasslands initially considered to be in "good" and "poor" condition.

prioritized to ensure an improvement in the long-term viability of the grassland. Planning for appropriate buffers and adjacent land uses, and seeking to promote active stewardship through thoughtful design are also recommended to achieve biodiversity objectives in this case.

Case Study 2. BSUD for a threatened reptile in an established urban environment

We consider here a hypothetical situation in which managers are considering options for retrospectively applying BSUD principles to an existing urban environment to improve the viability of the striped legless lizard, *Delma impar*. In this simulated example, a lizard meta-population exists across four small grassland patches of 0.5, 1, 1.5, and 3 ha, embedded in a suburban matrix and separated by distances of 200 to 450 m. The size and distribution of patches reflects those of grassland remnants within the western suburbs of Melbourne, Australia.

Biodiversity values

The striped legless lizard is a grassland endemic, listed as nationally vulnerable due to historical and current habitat clearance. Limited dispersal ability and habitat requirements mean this species is sensitive to urban development. This species is present at low densities (6 individuals/ha) at three of the four sites, but the long-term survival of the meta-population is thought to be threatened by poor dispersal and ongoing threats from the urban matrix, including predation by cats and decline in habitat quality. Additional values include the native grassland remnants, which are nationally endangered and provide important refuge for other native grassland species.

Biodiversity objectives

The primary biodiversity objective is to improve the viability of the striped legless lizard. This will be assessed over a 25-year time horizon using three metrics:
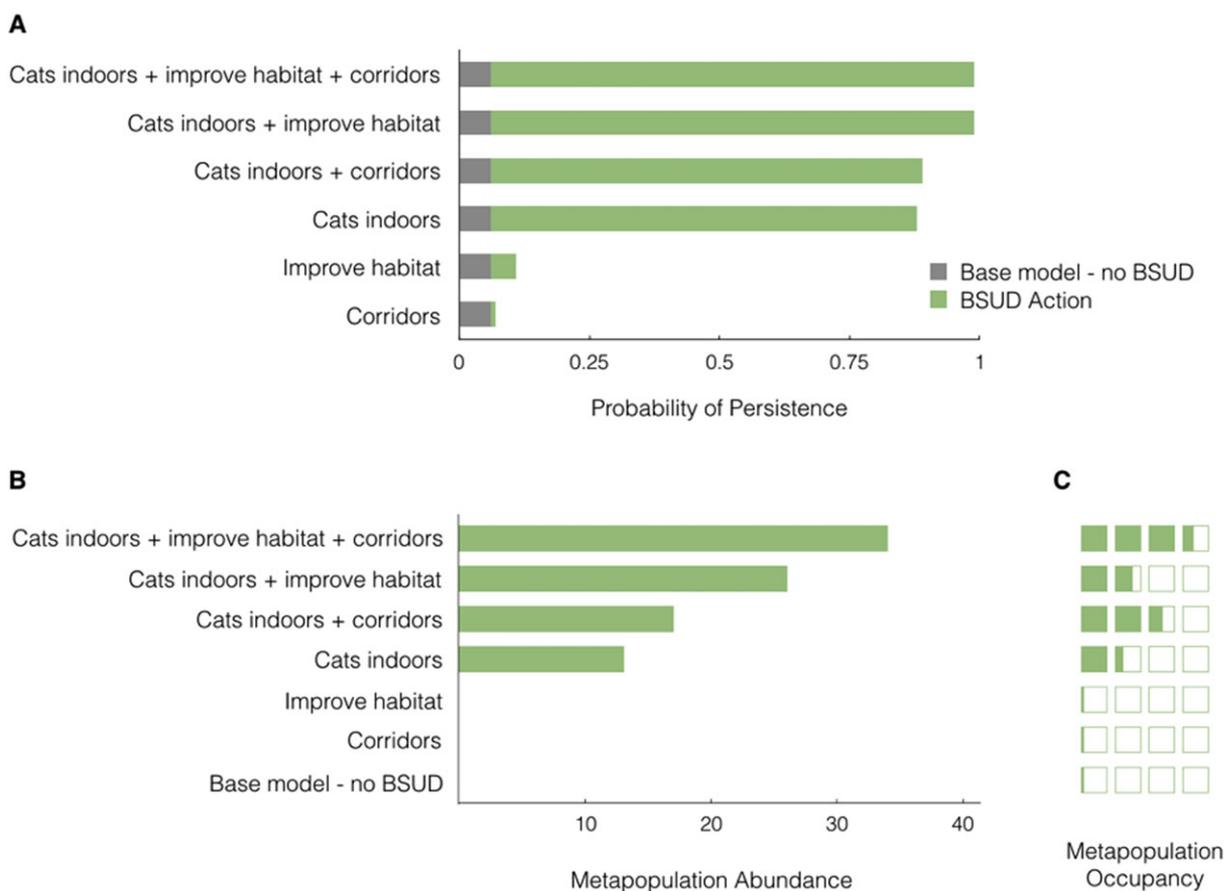
A

B

C

Figure 4 PVA results for the striped legless lizard, *Delma impar*, after 25 years. (A) Probability of meta-population persistence; (B) meta-population abundance; (C) meta-population occupancy (number of filled squares indicates the number of filled populations).

probability of persistence, population size, and probability of occupancy.

Development objectives

Potential BSUD actions should reflect the established nature of the surrounding suburban environment and community.

BSUD actions

Three potential BSUD actions were identified in discussion with two species experts: (1) creation of habitat corridors to facilitate dispersal; (2) improving habitat quality in existing patches; and (3) restricting domestic cats to indoors or confined outdoor runs.

Assessing BSUD

A formal PVA was used to assess the contribution of BSUD to lizard viability, and implemented in RAMAS

Landscape (2003 v 1.0). BSUD actions were simulated by: (1) allowing dispersal between patches, which occurs with decreasing probability as the distance between patches increases up to a maximum of 400 m; (2) increasing the carrying capacity of individual patches; and (3) reducing the proportion of individuals lost to predation from 0.50 to 0.25. The modelling process and results are provided in detail in the supplementary material.

Decide

When considering BSUD actions in isolation, decreasing predation through cat containment delivered the biggest benefit to the legless lizard, regardless of which evaluation metric was used (Figure 4). This action alone increased the probability of persistence from 0.06 to 0.88 (Figure 4A). The largest benefits were gained when all three BSUD actions were applied, although habitat improvement and the creation of habitat corridors contributed to substantial increases in meta-population

abundance and occupancy, respectively, when considered separately in combination with cat containment (Figure 4B, C).

The creation of corridors is likely to pose significant challenges in an established suburban environment where private land ownership is the dominant tenure. These results suggest that cat containment combined with habitat improvement in remnant patches can deliver remarkably good outcomes when evaluated using probability of persistence and abundance, however this comes at the expense of patch occupancy.

Discussion

We have presented a framework for incorporating ecological knowledge into the planning, design and development of urban environments. This framework makes three important advances in the field of urban conservation planning. First, it seeks to achieve onsite biodiversity gains, which will be necessary for reversing biodiversity decline, and further, is important for reconnecting urban residents with nature and exposing them to the benefits it provides (Soga & Gaston 2016). Second, by seeking to achieve biodiversity benefits in any development, BSUD rises above the dominant land sparing/sharing debate relating urban development patterns to biodiversity outcomes (Lin & Fuller 2013), which is scale-dependent and can be difficult to apply in practice because development patterns typically lie somewhere between sparing and sharing. Third, because it explicitly links urban design to measurable biodiversity outcomes, BSUD provides a flexible framework for developers and planners to make transparent trade-offs between biodiversity and other socioeconomic objectives.

However, BSUD alone is insufficient to conserve biodiversity in cities while they continue to densify and expand. Land sparing is important for protecting remnant habitat and maintaining some ecosystem services (Stott *et al.* 2015). Furthermore, many species will require large, well-connected habitat patches to survive (Beninde *et al.* 2015). To maximize urban biodiversity conservation outcomes, BSUD should be implemented alongside strategic land planning (e.g., Bekessy *et al.* 2012), including specification for housing densities that minimize the urban footprint. Research investigating the effectiveness of BSUD at different scales and housing densities will make a valuable contribution to current understanding.

Critical next steps for BSUD include establishing regulation for minimum standards, and identifying responsible authorities, appropriate bridging organizations and project champions to help build cross-sectoral relation-

ships and a trusted body of science. Incorporating BSUD into holistic performance tools, such as the Green Building Council of Australia's Green Star Communities and US Green Building Council's Leadership in Energy and Environmental Design, is a further opportunity.

Many questions remain. For example, what are appropriate targets for BSUD, and with whom will the responsibility for implementation lie? We believe it is reasonable to expect the proponent or developer to accept procedural and financial responsibility for implementing BSUD, as is the case for similar urban design schemes. Proponents could demonstrate adherence to biodiversity targets as part of the development approval process, with assessments undertaken independently by ecological consultants, either separately or as part of environmental impact assessments that are now standard precursors to development in many countries. PVAs are not beyond the capabilities of many ecological consultants; however, metrics such as abundance or probability of occupancy may suffice where data availability or technical expertise precludes viability assessment.

Science can provide information about the biodiversity benefits of BSUD, but decisions about performance targets, including which species and ecosystems to target and what minimum standards apply, are subjective and must be made by a regulatory authority on behalf of society. These targets would likely be guided by socioecological criteria, and BSUD offers a flexible framework in which biodiversity benefits can be transparently traded-off against other environmental, social and economic goals. Regardless of the target, BSUD has the potential to shape a new conception of urban landscapes, where species can thrive and residents reap the remarkable range of benefits that biodiversity can deliver.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Table S1. Key Biodiversity Sensitive Urban Design elements in different phases of urban development
Biodiversity sensitive urban design for native grasslands using expert elicitation
Biodiversity sensitive urban design for the striped legless lizard using population viability analysis

References

Bekessy, S.A., White, M., Gordon, A., Moilanen, A., McCarthy, M.A. & Wintle, B.A. (2012). Transparent planning for biodiversity and development in the urban fringe. *Landsc. Urban Plan.*, **108**, 140-149.

Bekessy, S.A., Wintle, B.A., Lindenmayer, D.B. et al. (2010). The biodiversity bank cannot be a lending bank. *Conserv. Lett.*, **3**, 151-158.

Beninde, J., Veith, M. & Hochkirch, A. (2015). Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. *Ecol. Lett.*, **18**, 581-592.

Burgman, M.A., McBride, M., Ashton, R., et al. (2011). Expert status and performance. *PLoS One*, **6**, e22998.

Cooper, C.B., Dickinson, J., Phillips, T. & Bonney, R. (2007). Citizen science as a tool for conservation in residential ecosystems. *Ecol. Soc.*, **12**, 11.

Driscoll, D.A., Banks, S.C., Barton, P.S., Lindenmayer, D.B. & Smith, A.L. (2013). Conceptual domain of the matrix in fragmented landscapes. *Trend Ecol. Evol.*, **28**, 605-613.

Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H. & Gaston, K.J. (2007). Psychological benefits of greenspace increase with biodiversity. *Biol. Lett.*, **3**, 390-394.

Gaston, K.J., Davies, T.W., Bennie, J. & Hopkins, J. (2012). REVIEW: Reducing the ecological consequences of night-time light pollution: options and developments. *J. Appl. Ecol.*, **49**, 1256-1266.

Goddard, M.A., Dougill, A.J. & Benton, T.G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. *Trend Ecol. Evol.*, **25**, 90-98.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., et al. (2008). Global change and the ecology of cities. *Science*, **319**, 756-760.

Hostetler, M.E. (2012). *The green leap: a primer for conserving biodiversity in subdivision development*. University of California Press, USA.

Ikin, K., Le Roux, D.S., Rayner, L., et al. (2015). Key lessons for achieving biodiversity-sensitive cities and towns. *Ecol. Manage. Restor.*, **16**, 206-214.

Ives, C.D., Lentini, P.E., Threlfall, C.G., et al. (2016). Cities are hotspots for threatened species. *Glob. Ecol. Biogeogr.*, **25**, 117-126.

Joseph, L.N., Maloney, R.F. & Possingham, H.P. (2009). Optimal allocation of resources among threatened species: a Project Prioritization Protocol. *Conserv. Biol.*, **23**, 328-338.

Keeney, R. (1994). Creativity in decision making with value-focused thinking. *Sloan Manage. Rev.*, **35**, 33–41.

Lenth, B.A., Knight, R.L. & Gilgert, W.C. (2006). Conservation value of clustered housing developments. *Conserv. Biol.*, **20**, 1445-1456.

Lin, B.B. & Fuller, R.A. (2013). FORUM: sharing or sparing? How should we grow the world's cities? *J. Appl. Ecol.*, **50**, 1161-1168.

Lundholm, J.T. & Richardson, P.J. (2010). MINI-REVIEW: habitat analogues for reconciliation ecology in urban and industrial environments. *J. Appl. Ecol.*, **47**, 966-975.

Lyytimäki, J. & Sipilä, M. (2009). Hopping on one leg–the challenge of ecosystem disservices for urban green management. *Urban Forest. Urban Green.*, **8**, 309-315.

Mata, L., Garrard, G.E. & Kutt, A.S., et al. (2016). Eliciting and integrating expert knowledge to assess the viability of the critically endangered golden sun-moth Synemon plana. *Austral Ecol.*, **42**, 297-308.

McCarthy, M.A., Andelman, S.J. & Possingham, H.P. (2003). Reliability of relative predictions in population viability analysis. *Conserv. Biol.*, **17**, 982-989.

McKinney, M.L. (2006). Urbanization as a major cause of biotic homogenization. *Biol. Conserv.*, **127**, 247-260.

Nassauer, J.I. (1995). Messy ecosystems, orderly frames. *Landsc. J.*, **14**, 161-170.

Pett, T.J., Shwartz, A., Irvine, K.N., Dallimer, M. & Davies, Z.G. (2016). Unpacking the people–biodiversity Paradox: a conceptual framework. *BioScience*, **66**, 576-583.

Radford, K.G. & James, P. (2013). Changes in the value of ecosystem services along a rural–urban gradient: a case study of Greater Manchester, UK. *Landsc. Urban Plan.*, **109**, 117-127.

Shanahan, D.F., Fuller, R.A., Bush, R., Lin, B.B. & Gaston, K.J. (2015). The health benefits of urban nature: how much do we need? *BioScience*, **65**, 476-485.

Soga, M. & Gaston, K.J. (2016). Extinction of experience: the loss of human–nature interactions. *Front. Ecol. Environ.*, **14**, 94-101.

Stanley, M.C., Beggs, J.R., Bassett, I.E., et al. (2015). Emerging threats in urban ecosystems: a horizon scanning exercise. *Front. Ecol. Environ.*, **13**, 553-560.

Stott, I., Soga, M., Inger, R. & Gaston, K.J. (2015). Land sparing is crucial for urban ecosystem services. *Front. Ecol. Environ.*, **13**, 387-393.

Taylor, B.D. & Goldingay, R.L. (2012). Facilitated movement over major roads is required to minimise extinction risk in an urban metapopulation of a gliding mammal. *Wildlife Res.*, **39**, 685-695.

Threlfall, C.G., Williams, N.S.G., Hahs, A.K. & Livesley, S.J. (2016) Approaches to urban vegetation management and the impacts on urban bird and bat assemblages. *Landsc. Urban Plan.*, **153**, 28-39.

Williams, N.S.G., Lundholm, J. & Scott MacIvor, J. (2014). FORUM: do green roofs help urban biodiversity conservation? *J. Appl. Ecol.*, **51**, 1643-1649.

Wintle, B.A., Bekessy, S.A., Venier, L.A., Pearce, J.L. & Chisholm, R.A. (2005). Utility of dynamic-landscape metapopulation models for sustainable forest management. *Conserv. Biol.*, **19**, 1930-1943.